Coastal Protection and Restoration Authority of Louisiana

2019 Operations, Maintenance, and Monitoring Closeout Report

for

Fritchie Marsh Restoration (PO-06)

State Project Number PO-06
Priority Project List 2

June 2020
St. Tammany Parish

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Suggested Citation:

Hymel, M. and B. Richard 2020. *2019 Operations, Maintenance and Monitoring Report for Fritchie Marsh Restoration (PO-06),* Coastal Protection and Restoration Authority of Louisiana, New Orleans, Louisiana. 53 pp, including Appendices.

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Preface

The Fritchie Marsh Restoration project (PO-06) was funded through the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) on the 2nd Priority Project List with the USDA-Natural Resources Conservation Service (NRCS) as the federal sponsor. The 2019 report will be the 4th and final (close-out) report to summarize monitoring and O&M activities conducted during the life of the project. This report includes monitoring data and Annual Maintenance Inspections available through 2019. Additional documents pertaining to the PO-06 project may be accessed on the CPRA website at: https://cims.coastal.louisiana.gov/outreach/ProjectView.aspx?-projID=PO-0006 or on the CWPPRA website at https://www.lacoast.gov/new/Projects-/Info.aspx?num=po-06 .

I. Introduction

The Fritchie Marsh Restoration project (PO-06) encompasses an area of intermediate to brackish marsh approximately 3 miles southeast of Slidell, Louisiana. The 6,291-ac (2,546-ha) area is bound by US Hwy 90 to the south and east, and LA Hwy 433 to the west and south (Figure 1) and is part of the Big Branch Marsh National Wildlife Refuge (NWR) complex. From 1956 to 1984, approximately 2,260-ac (34%) of emergent marsh within the project area were converted to open water, with the greatest loss occurring in the northern project area (USDA/NRCS 1997). This loss reflected a pattern of marsh deterioration from north to south due to a reduction of freshwater and sediment input into the northern part of the project area. Natural hydrologic patterns were disrupted by the construction of the perimeter highways and the W-14 Canal. The highway embankments isolated the marsh from the West Pearl River and restricted the inflow of freshwater, nutrients, and sediment, while saltwater from Lake Pontchartrain continued to enter the system through the W-14 canal and Little Lagoon during high tides and strong winds. Additionally, freshwater runoff from the area north of the project, which would historically spread overland over the marsh, became diverted through the W-14 Canal to Lake Pontchartrain. As a result, the project area converted from a predominantly fresh marsh in 1956 to a predominantly brackish marsh by 1990.

The objective of the Fritchie Marsh Restoration project was to reduce marsh loss by restoring more natural hydrologic conditions in the project area through management of available freshwater. Specific objectives were (1) to increase freshwater flow and promote water exchange into the area from the West Pearl River by enlarging the culvert at U.S. Highway 90 and dredging portions of Salt Bayou, and (2) to increase freshwater flow into the northern project area by diverting flow from the W-14 canal. During the project development phase, it was assumed that the PO-06 project would reduce the rate of wetland loss by 75% within the project area (WVA 1992). The originally proposed project area contained 5,924 acres with 3,436 acres (58%) of emergent wetlands. Land loss rates applied over the 20-year project were -69 ac/yr for ‘Future Without Project’ conditions and -17 ac/yr for ‘Future With Project’ conditions. At Year 20 of the project life, a projected 1,040 net acres of land was expected to be protected as a result of PO-06 construction.

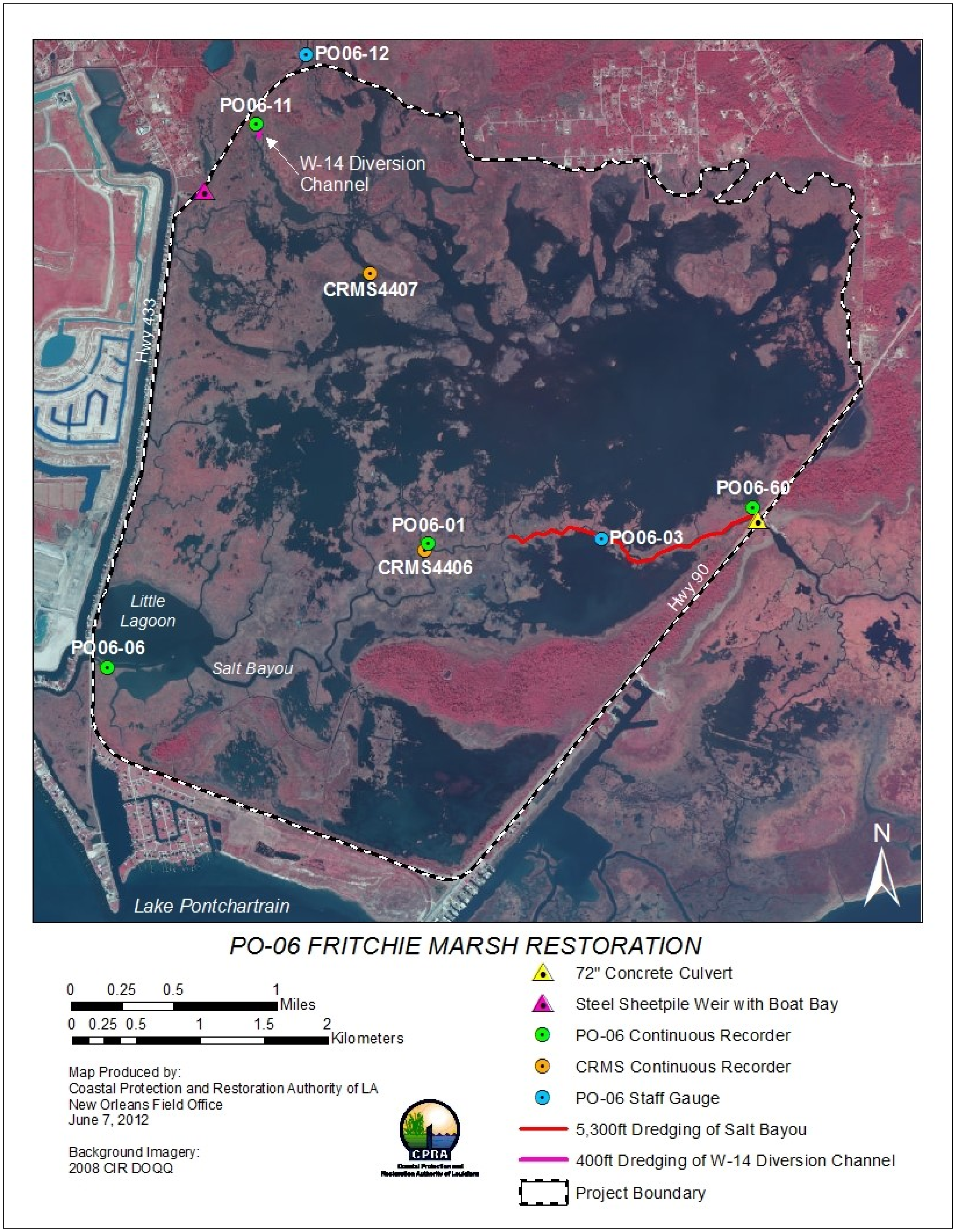


Figure 1. Fritchie Marsh Restoration (PO-06) project area boundary, construction features, continuous recorder locations, and CRMS site locations.

The Fritchie Marsh Restoration project was constructed in one phase beginning in October 2000 and ending in March 2001. The project has a 20-year economic life which began in March 2001.

The principal project features included:

- Installation (jack and bore) of a 72-inch diameter by 136-foot long concrete culvert under U.S. Highway 90, rock riprap lining of the Salt Bayou channel bottom and pipe outlets, and installation of 308 linear feet of sheet piling to form a bulkhead.
- Installation of a weir in the W-14 canal. The weir consists of 108 linear feet of sheet pile with a 20-foot wide boat bay.
- Dredging of approximately 400 linear feet of the W-14 diversion channel.
- Dredging of approximately 5300 linear feet of Salt Bayou from the US Hwy 90 culverts in a westward direction.

II. Maintenance Activity

a. Project Feature Inspection Procedures

The purpose of the annual inspection of the Fritchie Marsh Restoration project (PO-06) is to evaluate the constructed project features, to identify any deficiencies, and to prepare a report detailing the condition of project features and any corrective actions that may be needed. The inspection procedure consists of a site visit by land or water, as appropriate, with a visual inspection of the project features. If corrective actions are required, the CPRA shall provide a detailed cost estimate for engineering, design, supervision, inspection, and construction contingencies, and an assessment of the urgency of such repairs (LDNR 2002). The annual inspection report also contains a summary of past maintenance events (Section II. d.) and an estimated projected budget for the upcoming three (3) years for operation, maintenance and rehabilitation (Appendix A).

An inspection of the Fritchie Marsh Restoration project was conducted on November 8, 2017 by Clay Worley and Barry Richard of CPRA, and Doug Baker from NRCS. Access to the project area was accomplished via boat. Field inspection notes are shown in the Maintenance Inspection Report Check Sheet in Appendix B.

b. Inspection Results

<u>Hwy 90 Culvert and Stone Revetment</u>

The joint in the culvert on the dredged side of Salt Bayou (west side of US Hwy 90) appeared to be experiencing some separation (Appendix C: Photos 1 and 2). The bank scour reported in previous inspections appeared to have progressed very little, even with the extremely high water experienced during the spring of 2016.

Salt Bayou Dredging

The inspection team was not able to travel west on Salt Bayou from its intersection with US Hwy 90. An inspection in December 2015 noted that significant siltation of the bayou begins approximately 4,500 feet downstream of the culvert (west side of US Hwy 90) and remains shallow for several thousand feet beyond the end of dredging 5,300 feet downstream of the culvert. Due to the noted siltation issue the inspection team was not able to travel on Salt Bayou to observe the dredged section (Appendix C: Photo 3).

W-14 Weir

The weir structure was mostly surrounded by aquatic vegetation, but the boat bay was navigable. The visible portion of the handrails appeared to be in good condition. The warning signs were in very good condition (Appendix C: Photo 4). No maintenance is required in this area at this time.

W-14 Diversion Channel Dredging

The Diversion Channel is located upstream (north) of the weir and diverts water off of the W-14 Canal to the south through the project area. The inlet of the channel was filled in and unnavigable due to excessive amounts of aquatic vegetation (Appendix C: Photo 5). Emergent aquatic vegetation was present in the channel outfall.

c. Maintenance Recommendations

i. Immediate/ Emergency Repairs

Due to settlement and separation, the last joint of the culvert on the west side of US Hwy 90 will be removed. Additional riprap armoring will be used to dress the slope to minimize future erosion.

i. Programmatic/ Routine Repairs

No routine repairs are needed.

d. Maintenance History

The warning signs and directional arrows at the W-14 weir were repaired in 2015 due to weathering of the reflective surfaces and faded coloring. Eight (8) new sign faces and mounting hardware were purchased at a cost of $2,195.99 and installed by CPRA personnel over a two-day field effort.

III. Operation Activity

Operation activities are not required for this project.

IV. Monitoring Activity

a. Monitoring Goals

The objective of the Fritchie Marsh Restoration project is to restore more natural hydrologic conditions in the project area resulting in the protection of the existing marsh.

The following goals will contribute to the evaluation of the above objective:

1. Decrease rate of marsh loss.
2. Increase freshwater flow and promote water exchange into the area from the West Pearl River by enlarging the culvert at US Highway 90 and by dredging portions of Salt Bayou.
3. Increase freshwater flow into the northern project area by diverting flow from the W-14 canal.
4. Document species composition and relative abundance of vegetation to evaluate change over time.

b. Monitoring Elements

Land/Water Analyses

To determine changes in land to water ratios over the project life, color-infrared aerial photography was obtained of the project area and a 417-acre reference area during the pre-construction period (1996 and 2000) and post-construction period (2004, 2010, and 2016) (Appendix D1-D5). The 1996, 2000, 2004, and 2010 photography was 1:12,000 scale, color infrared (CIR) imagery acquired through project monitoring funds. The 2016 photography was 1-meter resolution, CIR digital ortho-imagery acquired through the Coast-wide Reference Monitoring System (CRMS) program. All acquired photography was geo-rectified, photo-interpreted, and analyzed by the USGS Wetland and Aquatic Research Center to determine land to water ratios using standard operating procedures documented in Steyer et al. (1995, revised 2000). All areas characterized by emergent vegetation, wetland forest, scrub-shrub, or upland were classified as land, while open water, aquatic beds, and non-vegetated mudflats were classified as water. Although the original monitoring plan stated that habitat analyses would be conducted, these were changed to land/water analyses upon the implementation of the CRMS program in 2003. The implementation plan of CRMS included a review of monitoring efforts on currently constructed CWPPRA projects, which concluded that habitat analyses on these projects should be converted to land/water analyses.

Land/water classifications were also conducted by the USGS Wetland and Aquatic Research Center for a 1-km^2 area encompassing CRMS sites 4406 and 4407 in years 2005, 2008, 2012, and 2016 (Appendix D6 and D7). These classifications were obtained from digital imagery with 1-meter resolution, acquired during the fall months (October to November). All areas characterized by emergent vegetation, upland, wetland forest, or scrub-shrub were classified as land, while open water, aquatic beds, and mudflats were classified as water.

Salinity

Salinity was sampled hourly using continuous recorders at four locations within the project area (Figure 1) using methods described in Folse et al. (2008, revised 2018). Three continuous recorders were placed in Salt Bayou and one was placed in the marsh near the diversion of the W-14 canal. The continuous recorder at each site was mounted on a wooden post in open water with sufficient water depths to inundate the recorder year round. Each continuous recorder station was serviced approximately once every month to clean and calibrate the recorder and to download the data. During processing, the data were examined for accuracy and loaded to the CPRA database, and are available for download from the CRMS website (http://www.lacoast.gov/crms2). Salinity monitoring occurred at these sites during the pre-construction period from 1997 to 2000 and during the post-construction period from 2001 to mid-2005. Hourly salinity and water level data have since been recorded at two CRMS sites within the project area, CRMS4406 and CRMS4407, from November 2007 to the present (Figure 1). CRMS4406 is located along Salt Bayou near the former site of project-specific station, PO06-01. CRMS4407 is located within the northern half of the project area.

Water Level

Water levels were measured hourly using the same four continuous recorders that were used for salinity monitoring (Figure 1). A staff gauge was installed next to each continuous recorder to compare recorded water levels to a known datum (NAVD88, Geoid 99). Water level data (ft NAVD88, Geoid 99) were collected during the pre-construction period from 1997 to 2000 and during the post-construction period from 2001 to mid-2005.

Hourly water level data (ft NAVD88, Geoid 12A) have since been recorded at two CRMS sites within the project area, CRMS4406 and CRMS4407, from November 2007 to the present (Figure 1). Marsh inundation during the CRMS period was calculated for each site relative to the mean marsh elevation surveyed in 2014.

Water Flow

To monitor the increased flow of water into the project area at the Salt Bayou/Hwy 90 culvert and at the diversion at the W-14 canal, hourly current meter data were collected by LSU at five stations near the same locations where continuous recorders were present. Flow volume estimates at each station were made using recorded current data, channel cross sections, and water level data from the associated continuous recorder station. The meters were deployed for a one year period prior to construction (October 1998 to January 2000) and for the same duration after construction (December 2001 to December 2002). Unfortunately, the flow data has been determined by CPRA to be unsuitable for analysis. A meeting was held in May 2005 in which representatives from LSU and CPRA, as well as an expert hydrologist from USGS, were present. Several anomalies in the data were discussed but were unable to be sufficiently resolved. This determination was based on several factors including unreasonably high observed flow rates during some periods, inability to confirm cross-sectional area calculations of the channel, and too many zero values in the post-construction data. According to the USGS expert, further problems were due to improper meter type and placement, as well as the absence of developing adequate index/mean velocity relationships. These relationships must be developed from flux measurements that change over time and under different flow conditions. The problems cannot be repaired through re-processing because the proper ground truth data were not collected.

Vegetation

Species composition, percent cover, and relative abundance were evaluated within 2-m x 2-m plots using a modified Braun-Blanquet sampling method (Mueller-Dombois and Ellenberg 1974, Folse et al. 2008, revised 2018) in 1997 and 2000 (pre-construction), and in 2004, 2007, 2010, 2013, and 2016 (post-construction). During the first survey in 1997, 25 plots were sampled; however, four additional plots were established in 1999 for a total of 29 plots. In subsequent sampling years, any plot that converted to open water was re-established within the nearest landmass and renamed by adding an 'A' to the end of the station name (i.e., PO06-23 was re-established as PO06-23A). This was to ensure that we would continue to characterize the vegetation throughout the project area, despite the loss of sampling plots. Nine of the original plots have converted to open water since sampling began.

Emergent marsh vegetation has also been sampled annually at the two CRMS sites within the project area (CRMS4406 and CRMS4407) since 2007. At each CRMS site, ten 2-m x 2-m sampling plots were randomly located along a 288-m transect and were sampled using the same method described above. Percent coverage data from the PO-06 stations and CRMS stations were summarized according to the Floristic Quality Index (FQI) method utilized by CRMS (Cretini et al. 2011), where cover is qualified by scoring species according to their tolerance to disturbance and stability within specific habitat types.

CRMS Supplemental

Additional data were collected at the two CRMS stations within the project area (CRMS4406 and CRMS4407), which can be used as supporting or contextual information for this project. Data types collected at CRMS sites include hydrologic, emergent vegetation, physical soil characteristics, discrete porewater salinity, marsh surface elevation change, vertical accretion, and land/water analysis of the 1-km^2 area encompassing the station (Folse et al. 2008, revised 2018). For this report, hydrologic, vegetation, and marsh surface elevation data from the two CRMS sites were used to assess conditions within the project area over the project life.

c. Monitoring Results and Discussion

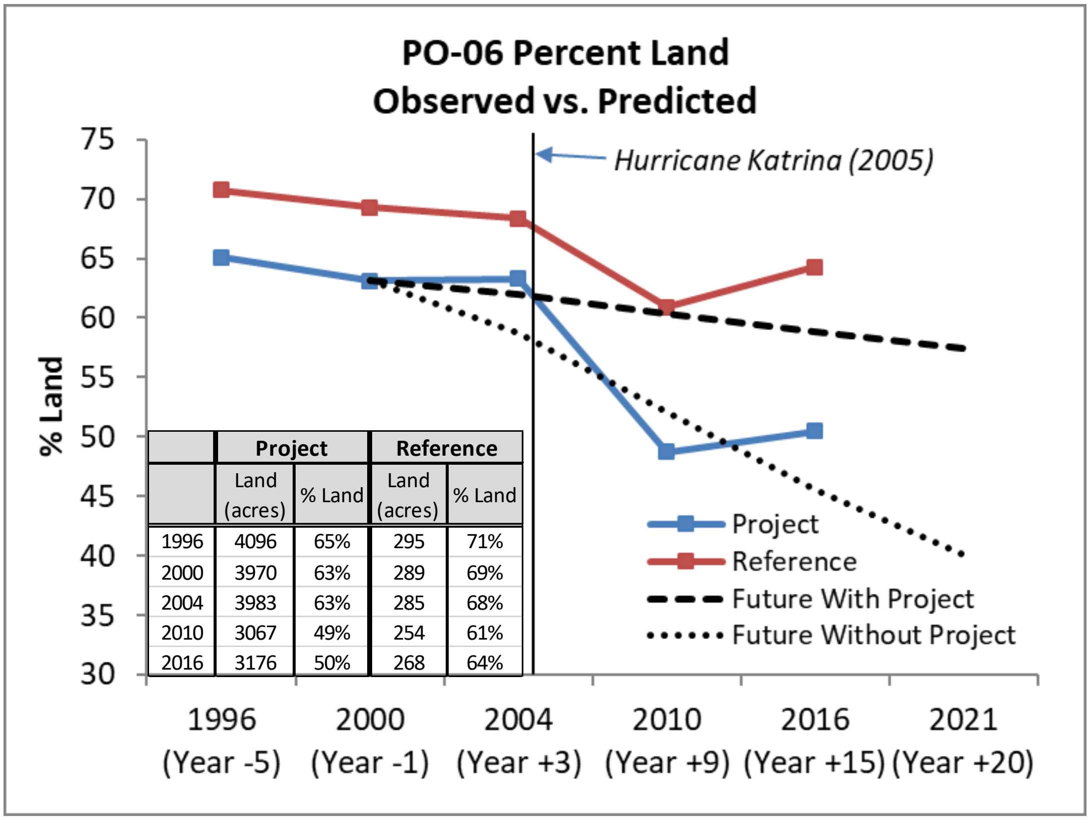
Land/Water Analyses

One of the specific monitoring goals for the Fritchie Marsh Restoration project was to reduce the rate of marsh loss within the project area. During the project design phase, it was predicted that the PO-06 project would reduce the rate of wetland loss by 75% within the project area, which was used to calculate project benefits at Year 20 of the project life (WVA 1992). The historic land loss rate applied for the 'Future Without Project' scenario was -69 ac/yr and the reduced land loss rate applied for the 'Future With Project' scenario was -17 ac/yr. Based on these loss rates, a projected 1,040 net acres of land was expected to be protected at Year 20 as a result of PO-06 construction.

To evaluate land changes within the project and reference areas over time, land/water analyses were conducted in 1996, 2000, 2004, 2010, and 2016 (Appendix D1-D5 and Table 1). There were 126 acres lost during the pre-construction period (1996-2000) at a rate of -32 ac/yr. This observed loss rate was 54% lower than the historic loss rate assumed during the WVA process, and may be a more accurate representation of land loss conditions just before the start of project construction. Total land acreage in 2000 within the project area just before the start of construction was 3,970 acres (63% of the total acreage), and the WVA land loss rates were applied to this observed 'Year 0' land acreage to project the 'Future With Project' and 'Future Without Project' acreages (Figure 2).

Table 1. Land/water analysis summary for the Fritchie Marsh Restoration (PO-06) project area and reference area from 1996 to 2016. *(Note: The 2004-2010 period includes impacts due to Hurricane Katrina (2005))*.

Year Range	Project			Reference		
	Land Change (acres)	% Change in Land Acreage	Loss/Gain Rate (acres/yr)	Land Change (acres)	% Change in Land Acreage	Loss/Gain Rate (acres/yr)
1996-2000 (Pre-construction)	-126	-3.1%	-32 ac/yr	-6	-2.0%	-2 ac/yr
2000-2004	+13	+0.3%	+3 ac/yr	-4	-1.4%	-1 ac/yr
2004-2010	-916	-23.0%	-153 ac/yr	-31	-10.9%	-5 ac/yr
2010-2016	+109	+3.6%	+18 ac/yr	+14	+5.5%	+2 ac/yr
Overall Post-construction (2000-2016)	**-794**	**-20.0%**	**-50 ac/yr**	**-21**	**-7.3%**	**-1.3 ac/yr**



	Project		Reference	
	Land (acres)	% Land	Land (acres)	% Land
1996	4096	65%	295	71%
2000	3970	63%	289	69%
2004	3983	63%	285	68%
2010	3067	49%	254	61%
2016	3176	50%	268	64%

Figure 2. Observed vs predicted percentage of land within the Fritchie Marsh Restoration (PO-06) project and reference areas.

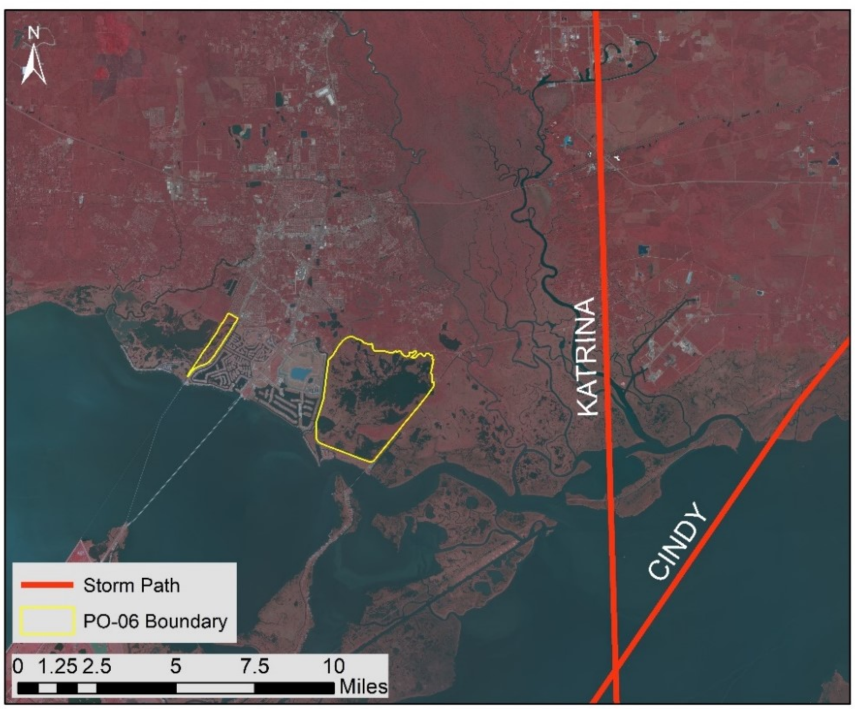


Figure 3. Storm tracks of Hurricane Katrina (August 2005) and Tropical Storm Cindy (July 2005) in relation to the Fritchie Marsh Restoration (PO-06) project and reference areas.

In the years immediately after construction (2000 to 2004), the acreage of land within the project area showed a gain of 13 acres and appeared to be following the trend of the 'Future With Project' acreage (Figure 2), while the reference area showed a slight loss of 4 acres. A significant loss of 916 acres, however, occurred within the project area during the following period (2004-2010), which represents a -23% decrease in land acreage. A land loss of -31 acres also occurred in the reference area during this period, and the change in % land acreage was proportionally smaller (-11%) than observed in the project area. During this period, the eyewall of Hurricane Katrina passed approximately 5.5 miles east of the project area on August 29, 2005 (Figure 3) with 120 mph sustained winds and hurricane force winds extending nearly 100 miles from the center of the eyewall at landfall (Knabb et al. 2005). High water mark data indicate the storm surge was 12 to 16 ft along the north shore of Lake Pontchartrain in St. Tammany Parish. Prior to Hurricane Katrina, Tropical Storm Cindy also passed to the east of the project area on July 6, 2005 (Figure 3).

Field observations made within the project area directly after Hurricane Katrina indicated significant land loss within the project area as a result of the storm. To determine the effects of Hurricane Katrina, USGS conducted an analysis comparing 2004 and 2005 Landsat 5 satellite imagery (Figure 4). This analysis showed a loss of 1,037 acres of land between 2004 and 2005, or approximately 22.5% of the pre-storm land acreage. This indicates that the 23% loss observed during the 2004-2010 period occurred primarily during the 2005 storm season. The post-Katrina imagery shows that a significant portion of the land loss occurred within the northeastern quadrant of the project area, which contained the most fragmented marsh before the storm. The highly fragmented areas of marsh within the project area were likely more vulnerable to storm effects than the reference area, which may explain why the losses within the reference area were of lesser magnitude.

In the most recent period of analysis (2010-2016, Years 9 to 15 post-construction), both the project and reference areas demonstrated gains in land acreage, indicating stabilization and recovery in the wake of Hurricane Katrina. During this period, the project and reference areas experienced land gains of +109 acres and +14 ac, respectively (Table 1, Figure 2), with the % increase in land acreage within the reference area (+5.5%) proportionally larger than in the project area. (+3.6%). Floating aquatic vegetation within both areas at the time of the 2016 imagery acquisition presented challenges during the analysis and may have slightly increased error in land estimations. Regardless, it is evident that the land acreage within the project area had stabilized and was demonstrating signs of recovery during this period. Land/water analyses of the two CRMS sites in the project area in 2005 (post-Katrina), 2008, 2012, and 2016 also demonstrate that land acreage in the project area was stable in the post-Katrina period (Appendix D6 and D7). CRMS4406 contained 76% land within the 1-km^2 area and showed no net change in land area from 2005 to 2016, while CRMS4407 showed a gain of +17.1 acres (+13.7%) within the 1-km^2 area from 2005 to 2016.

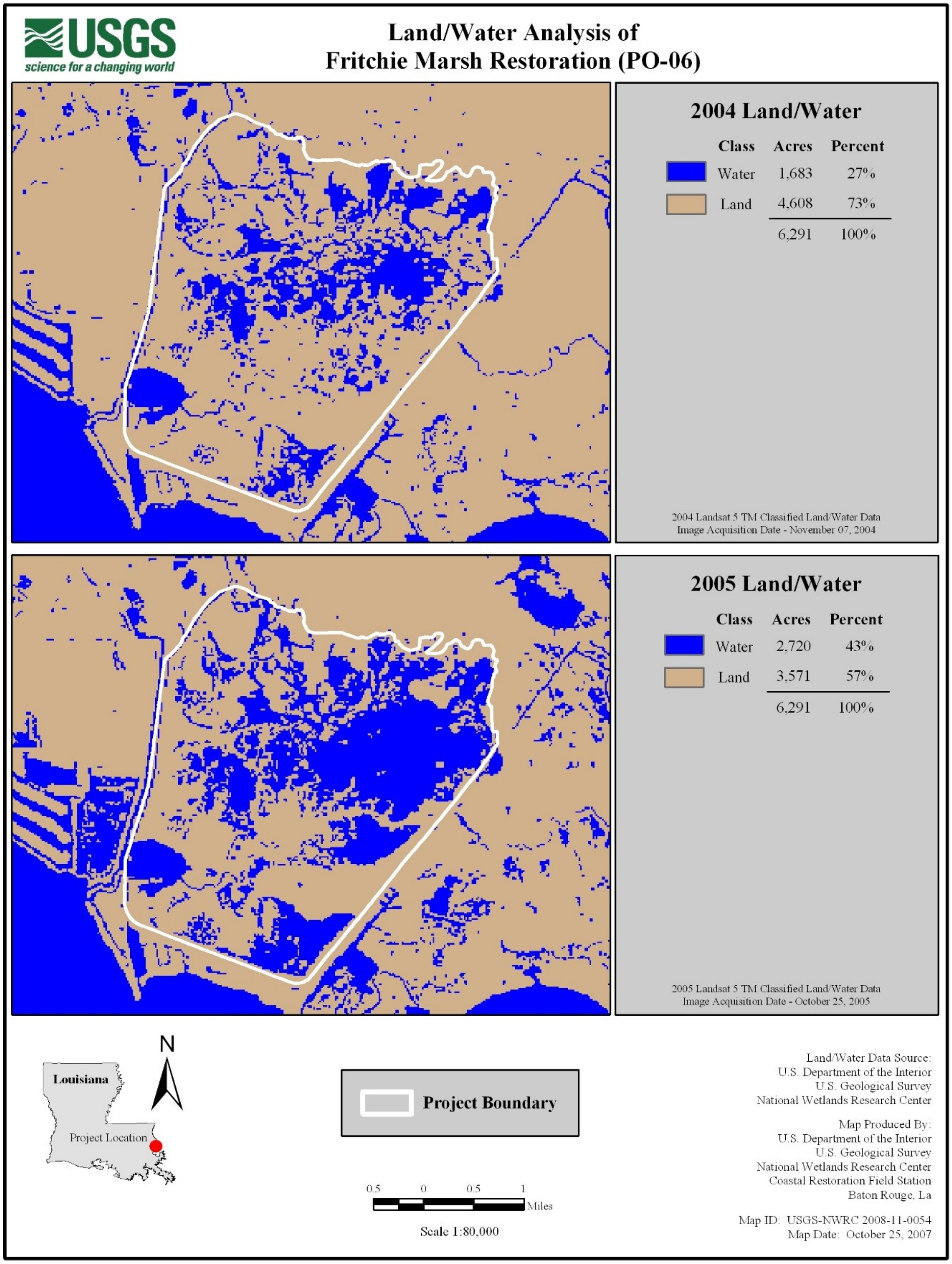


Figure 4. 2004 and 2005 land/water comparison of the Fritchie Marsh Restoration (PO-06) project area using Landsat 5 satellite imagery. The 2005 imagery was acquired two months after the passage of Hurricane Katrina.

The overall land loss rate observed within the project area through Year 16 of the project life was -50 ac/yr. This land loss rate is lower than the historic WVA land loss rate (-69 ac/yr) but greater than the land loss rate observed immediately pre-construction (-32 ac/yr). Because of the extreme effects of Hurricane Katrina, it is difficult to draw definite conclusions on project effectiveness from the land/water analyses. The decrease in the loss rate from -32 ac/yr before construction to +3 ac/yr from 2000 to 2004 indicates that the project may have been having a positive effect before Hurricane Katrina; however, a slight decrease in the loss rate was also observed within the reference area during this period. The project area demonstrated subsequent stability and small land gains in the most recent period (2010-2016); however, this too was also observed in the reference area. Although the land acreage is currently below the 'Future With Project' projections due to the hurricane-induced losses, the land acreage at Year 16 (2016) is 310 acres higher than the 'Future Without Project' projected acreage at Year 16. The hydrologic modifications associated with the project may have provided a protective benefit through enhanced resiliency to the impacts of the storm.

There are multiple dedicated dredging projects currently in the design and construction stages which will improve land to water ratios within the Fritchie Marsh. At the time of this report, construction of the New Zydeco Ridge BLH-Wet and Brackish Marsh Restoration project is nearly completed, which will directly increase land acreage within the PO-06 project area (Figure 5). This project is being constructed by the USACE to mitigate for impacts associated with construction of the Lake Pontchartrain and Vicinity (LPV) Hurricane Storm Damage Risk Reduction System (HSDRRS). Material dredged from Lake Pontchartrain is being used to create 159 acres of bottomland hardwood habitat flanked by 220 acres of marsh (160 acres to the south and 62 acres to the north) within the shallow, open water area north of Salt Bayou. During project design, it was determined that approximately 2 acres of existing marsh occurred within the proposed project area based on 2013 aerial photography (Trahan 2015). This will result in a net increase of 379 acres of land within the project area following construction. Another CWPPRA project proposed within the PO-06 boundary, the Fritchie Marsh Creation and Terracing project (PO-0173), is in the early design phase and will further increase land acreage within the Fritchie Marsh if constructed (https://cims.coastal.louisiana.gov/outreach/projects/ProjectView?projID=PO-0173).

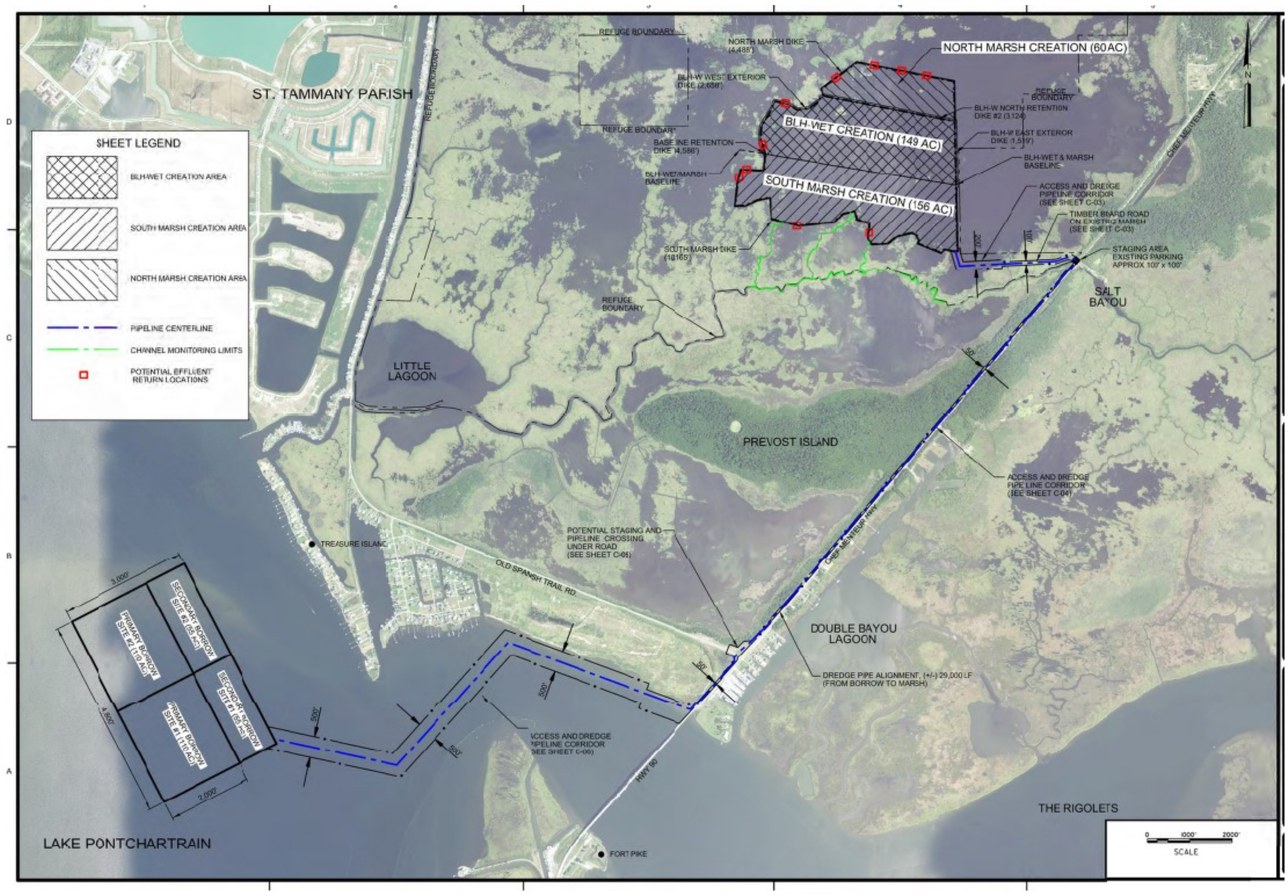


Figure 5. Location of the New Zydeco Ridge BLH-Wet and Brackish Marsh Restoration project area and borrow area. Acreages shown are for the interior fill areas only. Total constructed acreages including degraded containment dikes are expected to be 159 acres BLH-Wet, 62 acres North Marsh Cell, and 160 acres South Marsh Cell.

Salinity and Water Level

Two main goals of the Fritchie Marsh Restoration project were to increase freshwater flow into the northern project area from the W-14 Canal and into the eastern project area through the Hwy 90 culvert. To determine the effects of project features on hydrologic conditions, hourly salinity and water level data were collected at the following continuous recorder stations (Figure 1):

Station	Data collection period
PO06-01	6/1997 – 6/2005
PO06-03*	6/1997 – 3/1999
PO06-06	6/1997 – 6/2005
PO06-11	6/1997 – 6/2005
PO06-60*	3/1999 – 6/2005
CRMS4406	11/2007 – present
CRMS4407	11/2007 – present

*The continuous recorder at PO06-03 was removed because the water level dropped below the sonde sensor during normal low-water periods. The replacement station, PO06-60 was installed in deeper water closer to the Hwy. 90 culvert.

Discrete staff gauge readings were also recorded each month from March 1998 to June 2005 at the four PO-06 continuous recorder stations and at two additional staff gauge locations (Figure 1). Monthly mean salinity and water levels at the different recorder stations displayed similar responses to seasonal influences and storm events (Figures 6 and 7). Salinity was generally lowest near the Hwy 90 culvert (PO06-60) and highest on the western side of the project area where exchange with Lake Pontchartrain occurs (PO06-06). Salinity and water level spikes resulted from several tropical events including Tropical Storm Frances/Hurricane Georges in 1998, and Hurricanes Gustave and Ike in 2008, but were generally not prolonged. A prolonged drought, however, occurred from late 1999 through late 2000 (Figure 8) with all stations experiencing elevated salinities during most of this period. The end of the drought occurred just before the completion of construction in March 2001.

Continuous salinity and water level data through 2005 were analyzed using a 2 X 4 BACI factorial analysis of variance (ANOVA) in which an interaction between the main effects is tested for statistical significance (Stewart-Oaten et al. 1986, Underwood 1994, Smith 2002). The main effects were defined as *period* (pre-construction vs. post-construction) and *location* (station ID). The construction date used to define the pre- vs post-construction periods was March 1, 2001. A standard BACI analysis uses a 2 X 2 factorial treatment structure, with the individual stations representing spatial replication within the two levels of the Control-Impact (CI) treatment (i.e. reference area and project area). However, this project was designed without reference stations, so the four stations were compared with each other using *location* as a random effect and with no single station designated purely as a reference station. The only additional assumption needed is that if the project had an impact it would apply unevenly among the four stations.

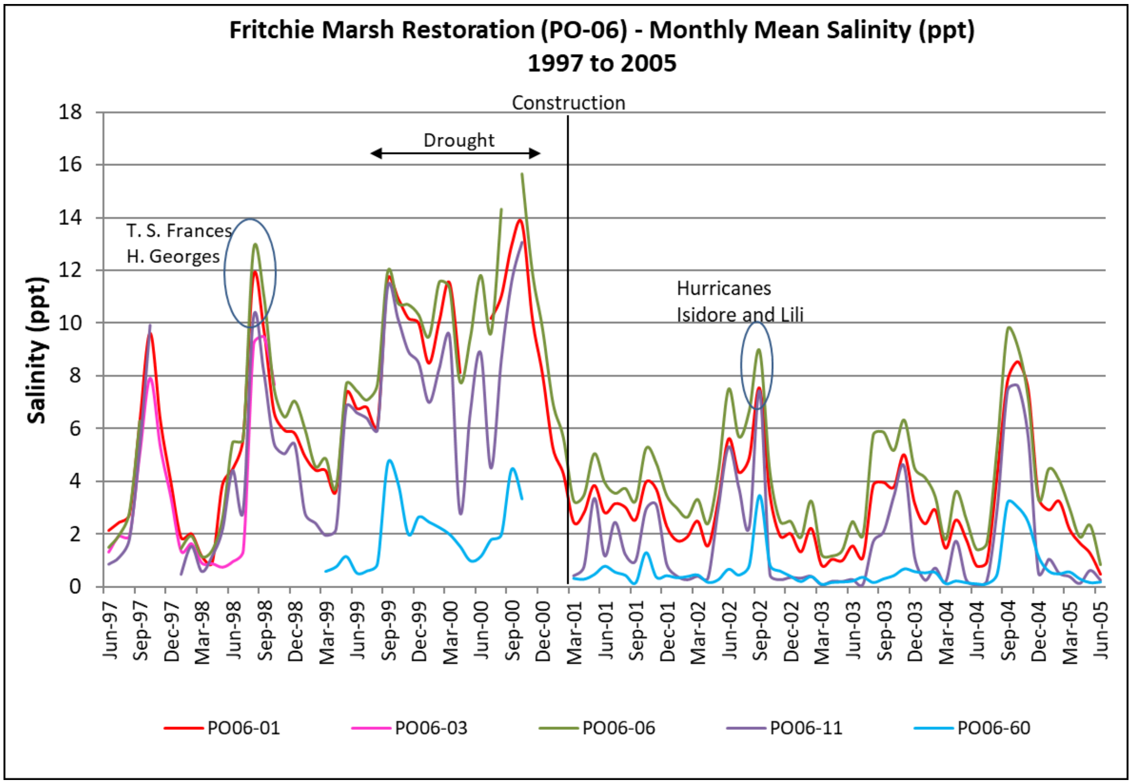


Figure 6. Monthly mean salinity for all continuous recorder stations within the Fritchie Marsh Restoration (PO-06) project area from 1997 to 2005.

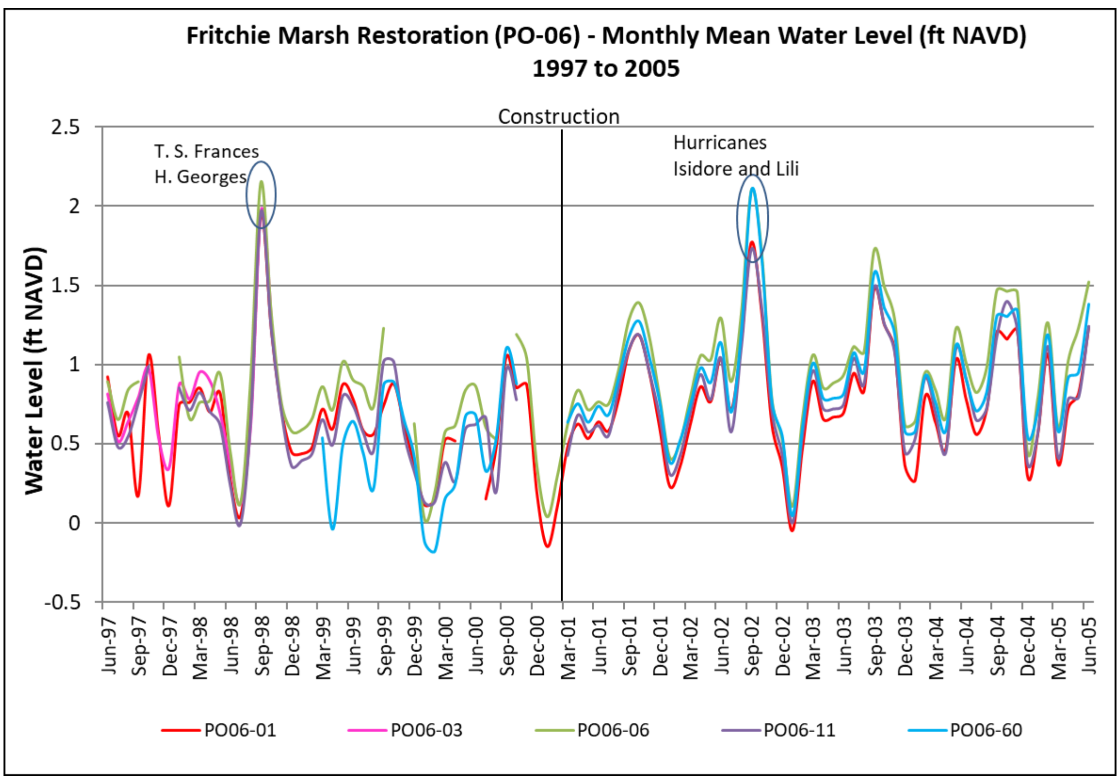


Figure 7. Monthly mean water level (ft NAVD88, Geoid99) for all continuous recorder stations within the Fritchie Marsh Restoration (PO-06) project area from 1997 to 2005.

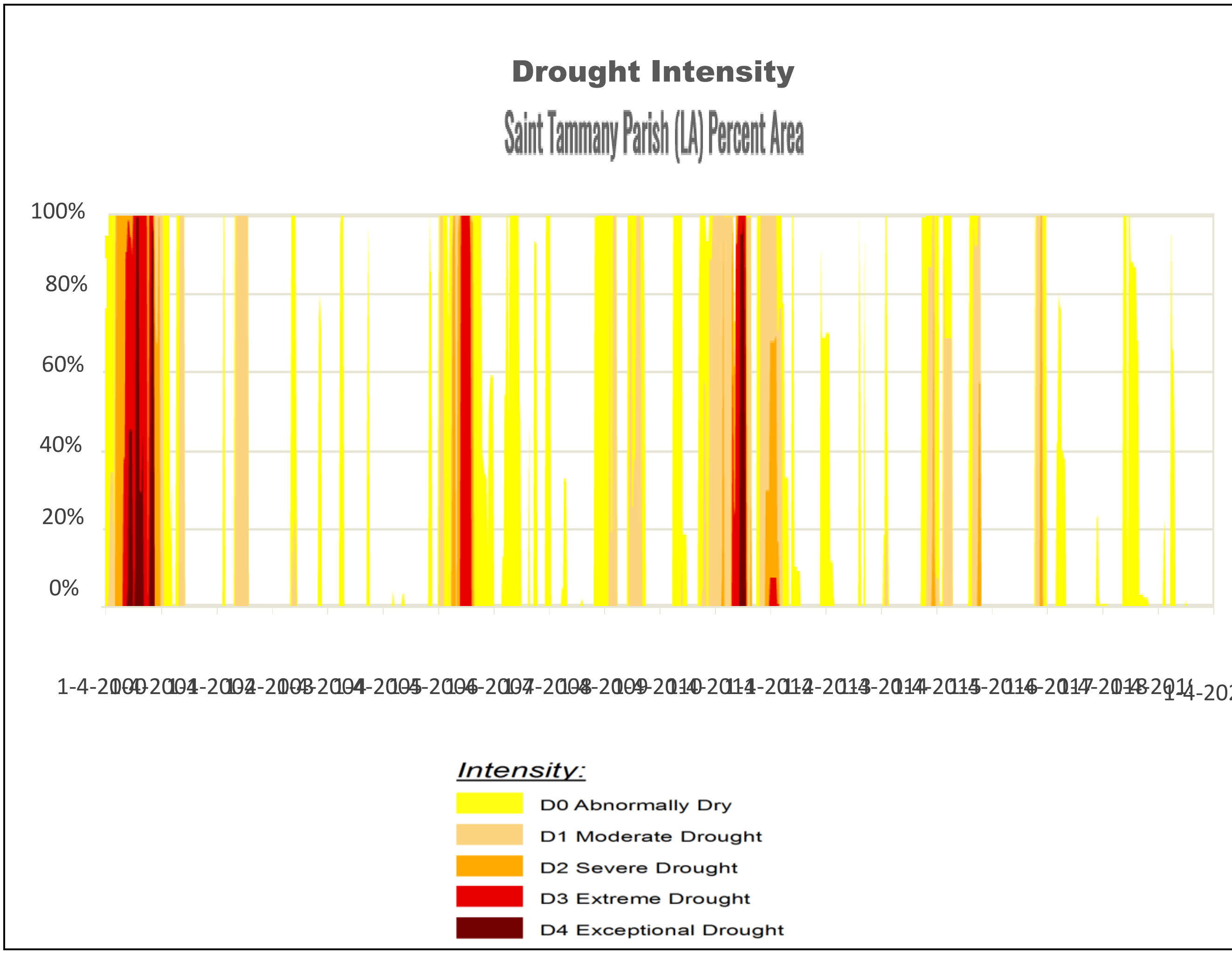


Figure 8. Drought intensity for St. Tammany Parish, Louisiana from January 2000 to August 2019. Map courtesy of the National Drought Mitigation Center (NDMC).

The statistical model depends on simultaneity of measurements among the various stations, treating each week in the study as a temporal block. Hourly salinity and water level measurements were aggregated into weekly means, with one week being sufficient to average out temporal lags among the stations during tidal and meteorological events. An additional advantage to using weekly means (versus hourly means) is that they exhibit less serial correlation, i.e., greater sample independence, which is an important underlying assumption of the statistical model. Hourly measurements were first transformed into common logarithms in order to better approximate the assumptions of normal distribution and uniform variance before being aggregated into weekly means.

The data show that the mean weekly salinity was lower and water level was higher at all four continuous recorder stations during the post-construction period (Figures 9 and 10). These data showed a significant interaction ($p<0.0001$) between stations in both the salinity

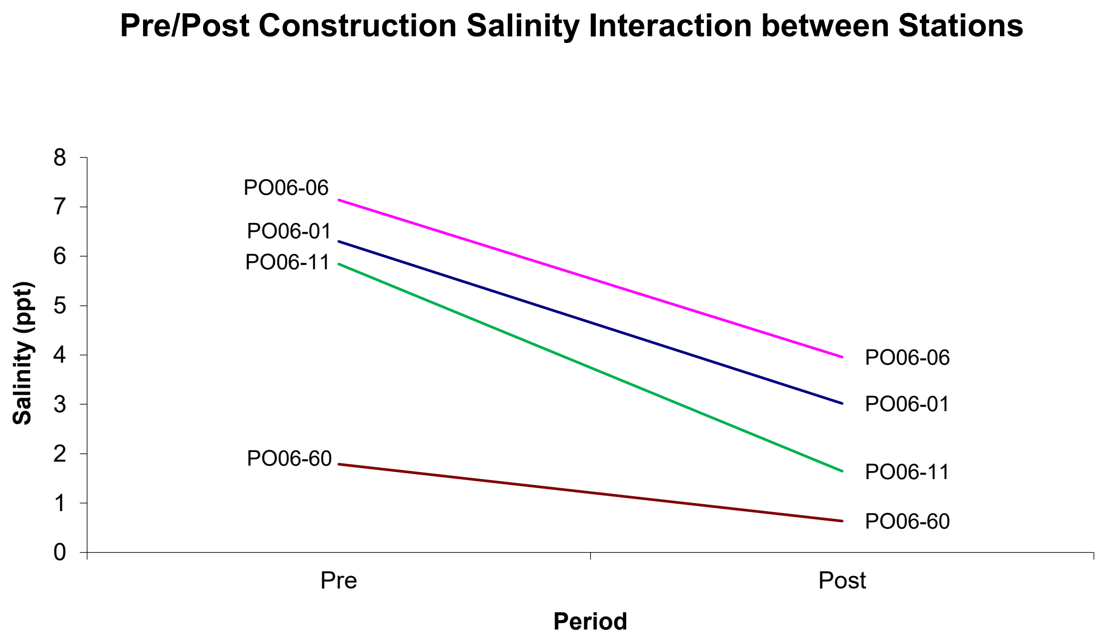


Figure 9. Interaction of mean weekly salinity during pre-construction and post-construction periods between four continuous recorder stations in the Fritchie Marsh Restoration (PO-06) project area. A significant interaction ($p<0.0001$) between stations was detected indicating a project effect.

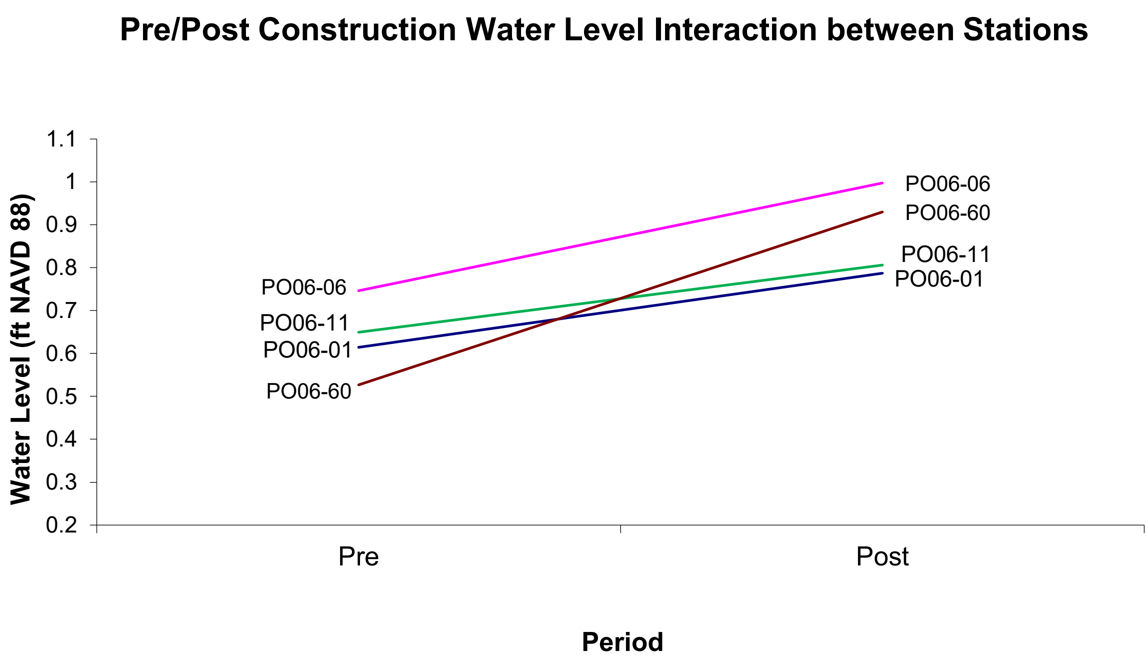


Figure 10. Interaction of mean weekly water level during pre-construction and post-construction periods between four continuous recorder stations in the Fritchie Marsh Restoration (PO-06) project area. A significant interaction ($p<0.0001$) between stations was detected indicating a project effect.

and water level analyses. The significant *period* by *location* interaction indicates that the relative magnitude of changes in salinity and water level was different between stations indicating a project effect. These effects show up graphically as lines out of parallel in Figures 9 and 10. Interpretation of these results is complicated by the intense drought from September 1999 to December 2000, which led to increased salinity during the pre-construction period (Figure 8). The statistical design controls against this kind of nuisance fluctuation only under the assumption that the four sites would respond equally to the drought. In order to test this assumption, the analysis was repeated with the drought period removed. The *period* by *location* interaction was again found to be significant (p<0.0001) indicating that there was a significant project effect despite the occurrence of the drought.

Another potential complication is that the analysis may have created an interaction purely as an artifact of the low pre-construction salinity at Station 60, which is located near the 72-inch culvert (Figure 9). Testing the *period* by *location* interaction allows inference as to whether the post-construction drop in salinity at all of the stations may be attributed to project construction and not to a general downward fluctuation over the 8-year monitoring period. While the other stations all decreased in salinity by 3 to 4 ppt, Station 60 began with a mean pre-construction salinity already at 2 ppt and therefore lacked the range necessary to match this trend. Although the log transformation compensates for this, the analysis was repeated on the drought-deleted data with Station 60 removed to test whether the significant interaction was an artifact of the low salinity at Station 60. Again, the *period* by *location* interaction was significant ($p<0.0001$) indicating a project effect at the remaining stations. Station 11, which is located near the W-14 weir, experienced a greater drop in salinity (i.e., steeper slope) than stations 01 and 06. This indicates that the weir may be having a positive effect on the salinity in the area near Station 11. The decrease in salinity was very similar at Stations 01 and 06, which indicates that the salinity at these stations is being affected by the project almost equally.

The interaction of mean water level between stations shows strong evidence of a project effect at Station 60 near the Hwy 90 culvert (Figure 10). Mean water level at this station was effectively doubled in the post-construction period. The magnitude of water level change was much greater at this station than at the other three stations, indicating that the addition of the culvert had a significant effect on water level. In contrast, the interaction results indicate that the W-14 weir has had comparatively less impact on water levels in the project area. Station 11, which is located near the weir, experienced an increase in water level very similar to that of Station 01. Station 06 experienced a slightly greater increase in water level than Stations 11 and 01. It should be noted, however, that the direct purpose of the weir was to reduce salinity in the marsh and not necessarily to increase water levels. Discrete water level readings recorded at 6 staff gauges on a monthly basis (at the four recorder stations plus two additional stations) confirmed a post-construction increase in water level at all stations except PO06-03; however, the increase was not significant for any of the stations ($p>0.05$) (Figure 11). It should be noted that there were fewer readings from PO06-03 in both the pre-construction and post-construction periods due to difficulty accessing the station during low water periods.

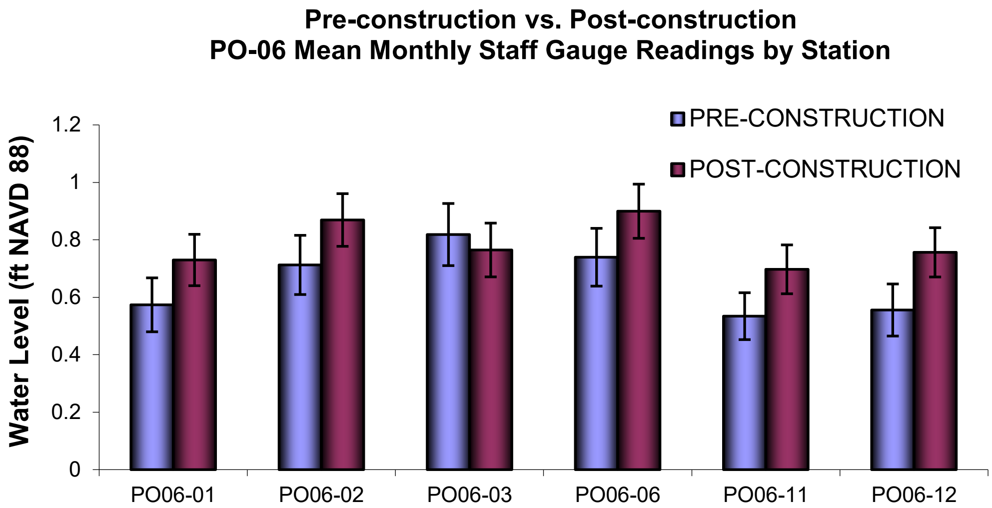


Figure 11. Mean of monthly staff gauge readings at the six staff gauges located in the Fritchie Marsh (PO-06) project area during the pre-construction (3/98-2/01) and post-construction (3/01-6/05) periods.

Although salinity and water level monitoring ended at the PO-06 sites in 2005, hydrographic data collection has been ongoing at the two CRMS sites in the project area since November 2007 (Table 2). CRMS4406 is located mid-way along Salt Bayou in nearly the same location as former site PO06-01, while CRMS4407 is located in the northern project area nearest to former site PO06-11 (Figure 1). Mean annual salinity during the CRMS data collection period (2008-2018) was 4.0 ppt at CRMS4406 and 2.1 ppt at CRMS4407 with the peak salinity occurring during a period of drought in 2011 (Figure 8). Mean annual salinity during the 2011 drought year, however, was approximately 5 ppt lower than observed during the extreme pre-construction drought in 2000. A weak trend of decreasing salinity (Figure 12) was observed during the CRMS data collection period (r^2=0.3); however, this trend is not unique to the PO-06 project area as an even stronger trend (r^2=0.7) was observed at CRMS sites within the nearby Main Unit of the Big Branch NWR (CPRA 2019). During a post-Hurricane Katrina inspection of the project in March 2006, it was noted that large amounts of sediment had been deposited into Salt Bayou between the hydrographic monitoring location (PO06-01/CRMS4406) and the Hwy 90 culvert during the storm. Subsequent project inspections have determined that the flow has been maintained through this area of Salt Bayou although it may become seasonally impeded by dense floating aquatic vegetation and during extreme low water periods. Since salinity fluctuations appear similar between CRMS sites in the north and south project areas and salinities within the intermediate range have been maintained, it appears that the project is continuing to function as designed.

Table 2. Summary of annual salinity and water level data collected at CRMS sites within the Fritchie Marsh Restoration (PO-06) project from 2008 to 2018.

Station	Year	Mean Salinity (ppt)	Max Salinity (ppt)	Mean Water Level (ft NAVD, Geoid12A)	Max Water Level (ft NAVD, Geoid12A)	Mean Flooding (ft)	% Time Flooded
CRMS4406-H01	2008	4.72	18.60	0.48	4.51	-0.12	39.88
	2009	4.19	15.70	0.49	3.44	-0.11	45.60
	2010	3.48	12.09	0.38	2.16	-0.22	43.61
	2011	5.49	22.24	0.35	3.71	-0.25	35.42
	2012	4.52	17.90	0.61	6.33	0.01	60.17
	2013	3.57	13.30	0.70	2.03	0.13	66.72
	2014	3.54	17.01	0.47	1.78	0.00	46.62
	2015	4.94	20.64	0.61	3.10	0.14	58.46
	2016	2.82	14.60	0.85	2.73	0.38	78.81
	2017	2.74	12.99	0.74	3.29	0.27	67.12
	2018	3.56	14.25	0.66	3.45	0.18	62.16
CRMS4407-H01	2008	2.60	10.32	0.64	4.65	-0.49	36.30
	2009	2.13	10.69	0.73	2.72	-0.40	49.64
	2010	1.92	7.88	0.51	2.23	-0.62	39.08
	2011	3.54	14.23	0.41	3.81	-0.72	27.81
	2012	2.21	8.77	0.68	6.54	-0.45	50.02
	2013	1.49	6.11	0.73	2.02	-0.28	58.20
	2014	2.04	7.93	0.53	1.77	-0.08	38.04
	2015	2.33	10.75	0.66	3.10	0.05	49.12
	2016	1.28	6.82	0.87	2.66	0.26	69.49
	2017	1.49	7.40	0.82	3.33	0.21	60.33
	2018	1.47	9.26	0.68	3.32	0.07	52.35

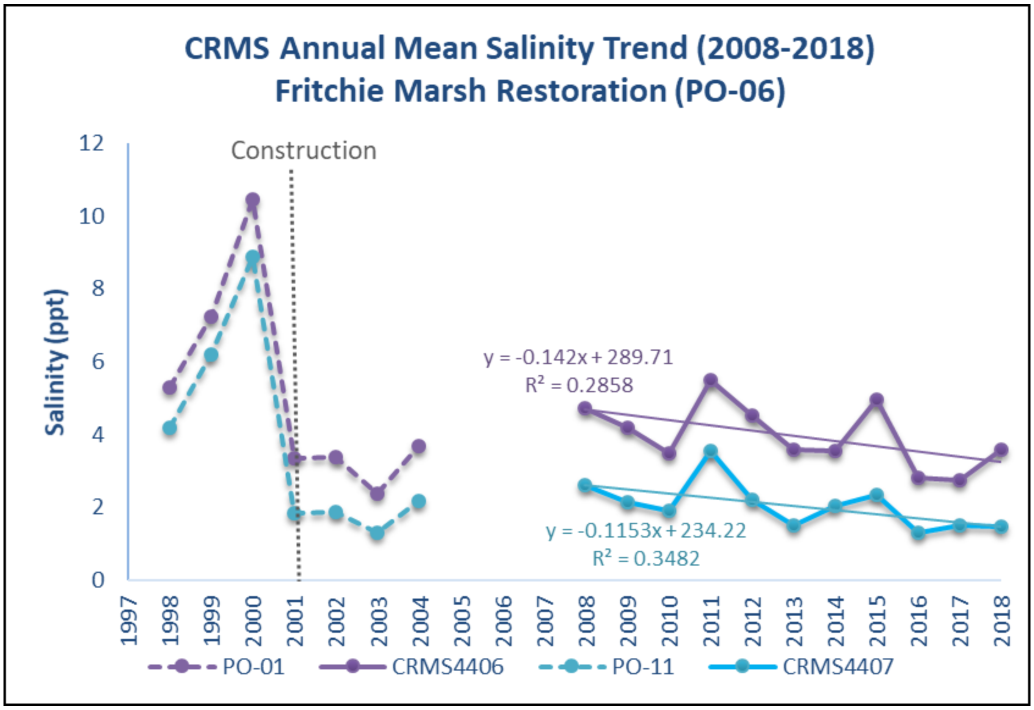


Figure 12. Trend in mean annual salinity (ppt) at CRMS sites within the Fritchie Marsh Restoration (PO-06) project from 2008 to 2018. Pre-construction salinities are shown for reference.

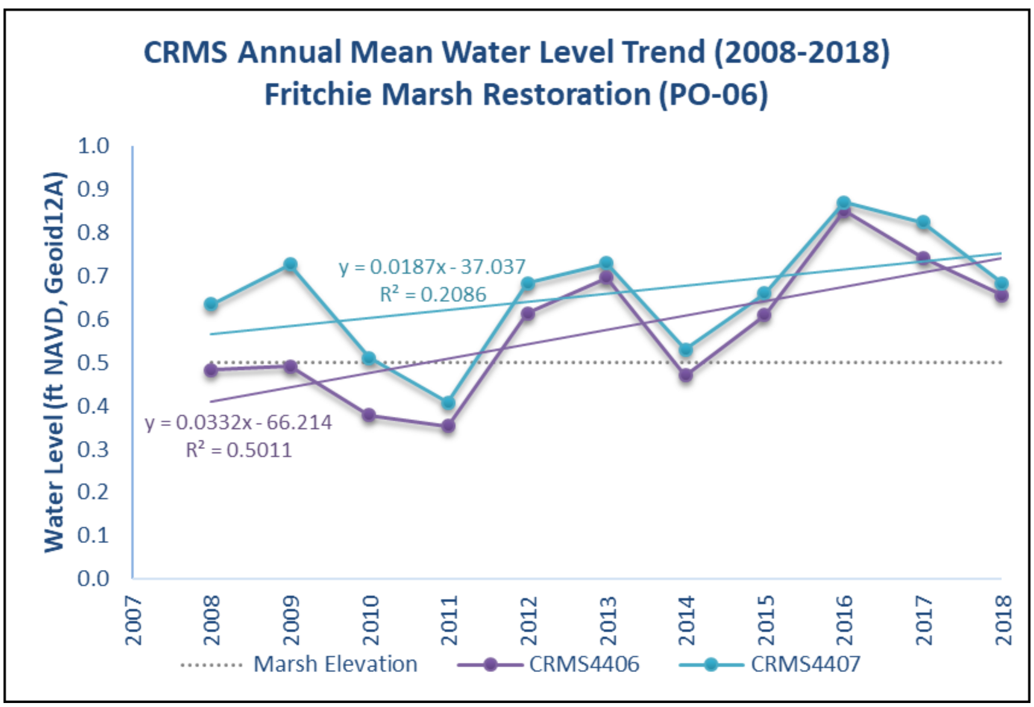


Figure 13. Trend in mean annual water level (ft NAVD88, Geoid12A) at CRMS sites within the Fritchie Marsh Restoration (PO-06) project from 2008 to 2018.

Mean annual water level during the CRMS data collection period was 0.58 ft NAVD88 (Geoid12A) at CRMS4406 and 0.66 ft at CRMS4407 with the highest water year occurring in 2016 (Figure 13). A trend of increasing water levels was observed over the CRMS period, [r^2=0.5 (CRMS4406), r^2=0.2 (CRMS4407)], which was also observed at nearby CRMS sites (CPRA 2019). Inundation during the CRMS period was calculated for each site relative to the mean marsh elevation surveyed in 2014 [0.47 ft at CRMS4406 and 0.61 ft at CRMS4407 (NAVD88, Geoid12A)]. Relative to this static marsh elevation, mean annual percent time flooded was 55% at CRMS4406 and 48% at CRMS4407; however, the percent time flooded has increased over time during the CRMS data collection period reflecting the increasing trend in mean water level (Figure 14). Percent time flooded ranged from 35% in 2011 to 79% in 2016 at CRMS4406 and from 28% in 2011 to 69% in 2016 at CRMS4407. Although increased inundation has been shown to reduce productivity within *S. patens* marshes (Snedden et al. 2015), measurements of vertical changes of the marsh surface over time at both CRMS sites using the rod-surface elevation table (RSET) technique developed by Cahoon et al. (2002a and 2002b) indicate a stable marsh surface elevation within Fritchie Marsh during the CRMS period with a slight increase in surface elevation observed at both sites. Surface elevation change rates were estimated to be +0.37 cm/yr (+0.012 ft/yr) at CRMS4406 and +0.13 cm/yr (+0.004 ft/yr) at CRMS4407 based on 11 years of RSET data from 2009 to 2019. The long-term accretion rate of sediment measured through the application of feldspar clay to the marsh surface (Folse et al. 2018) was +1.08 cm/yr (0.035 ft/yr) at CRMS4406 and +0.8 cm/yr (0.026 ft/yr) at CRMS4407, which was greater than the observed net increase in surface elevation. This indicates that subsidence processes are occurring but the rate of accretion has outpaced subsidence rates within the Fritchie Marsh during the data collection period. The stability of the marsh surface within Fritchie Marsh will provide some resilience to the trend of increasing water levels, and although inundation has increased it remains within the optimum range (10-90%) for primary productivity within intermediate marsh (Visser et al. 2004).

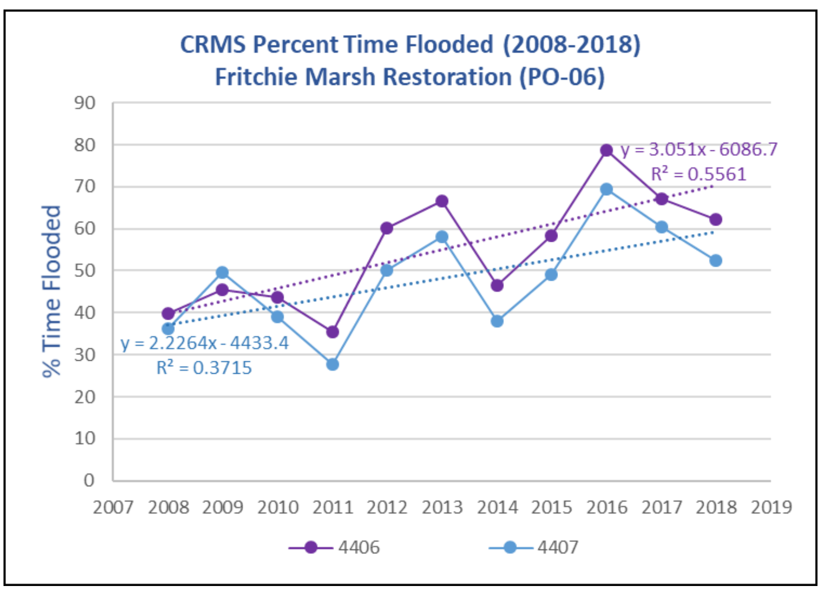


Figure 14. Percentage of time flooded annually at CRMS sites within the Fritchie Marsh Restoration (PO-06) project from 2008 to 2018.

Vegetation

Pre-construction vegetation surveys within the Fritchie Marsh project area were conducted in late summer/early fall of 1997 and 2000, and post-construction surveys were conducted in 2004, 2007, 2010, 2013, and 2016 within 29 (4-m^2) sample plots (Figure 15). Just before PO-06 construction, a decrease in total percent cover of vegetation was observed during the 2000 survey, presumably in response to the extreme drought (Figure 16). Since that time, vegetative composition and abundance has been highly stable over the life of the project. The project area was dominated by *Spartina patens* (saltmeadow cordgrass) in all survey years in terms of both frequency of occurrence and mean percent coverage. *S. patens* was found within 90-100% of the plots in each of the survey years (Table 3). Other commonly occurring species included *Vigna luteola* (hairypod cowpea), *Distichlis spicata* (saltgrass), *Juncus roemerianus* (needlegrass rush), *Polygonum* spp. (knotweed), *Lythrum lineare* (wand lythrum), and *Shoenoplectus americanus* (chairmaker's bulrush). The total number of species observed ranged from 21 to 34, with the lowest number of species found in 2000 following the severe drought. Total percent cover of vegetation was greatest in 1997, the first year sampled, and was lowest in 2000 following the drought (Figure 16). Overall mean percent cover of vegetation within the project plots remained relatively stable from 2000 to 2016 and ranged from 73 to 87% (Figure 17); however, it should be noted that nine of the original 29 stations had converted to open water by 2010 and were re-established within the nearest land mass. When calculated using the original 29 stations, mean percent cover drops below 60% in the post-Katrina sample years (2007-2016) (Figure 17). Most of these plots were lost due to the continued enlargement of the open water area in the eastern half of the project area (Figure 15).

Vegetation was also surveyed annually from 2007 to 2018 at the two CRMS sites within the project area, CRMS4406 and CRMS4407 (Figure 15). Ten 2 x 2-m plots were sampled along a transect within a 200-m^2 area at each CRMS site. Species composition and abundance at CRMS4406, which is located mid-way along Salt Bayou, was similar to the PO-06 sites (Figure 18), with *S. patens* as the dominant species in all years. Other commonly occurring species included *S. americanus* and *D. spicata*. At CRMS4407, which is located in the northwestern portion of the project area, the vegetation transect runs partially through a dense, monospecific stand of *Phragmites australis* (common reed) (Figure 19). Mean percent cover of *P. australis* at CRMS4407 has remained between 30-40% since 2007, but dropped slightly in 2018 to 27%. Species composition and abundance within the plots outside of the *P. australis* stand are highly variable and are more characteristic of fresh to intermediate marsh. Mean percent cover of vegetation measured at both CRMS sites has not demonstrated any significant trends over time and has fluctuated between 62-90% at CRMS4406 and between 64-96% at CRMS4407, which is consistent with the mean percent cover observed at the PO-06 sites during that time period (Figure 20).

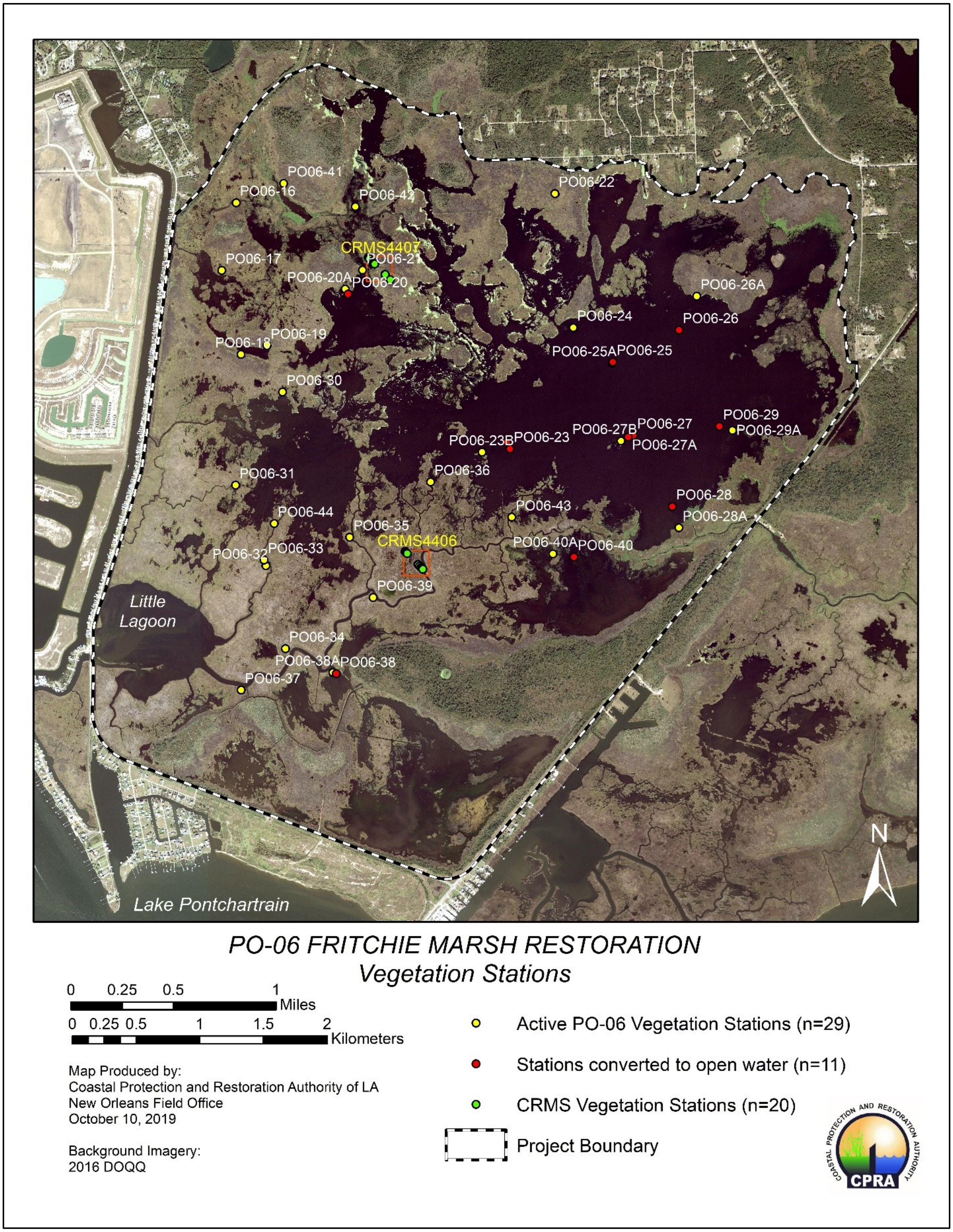


Figure 15. Vegetation stations located within the Fritchie Marsh Restoration (PO-06) project.

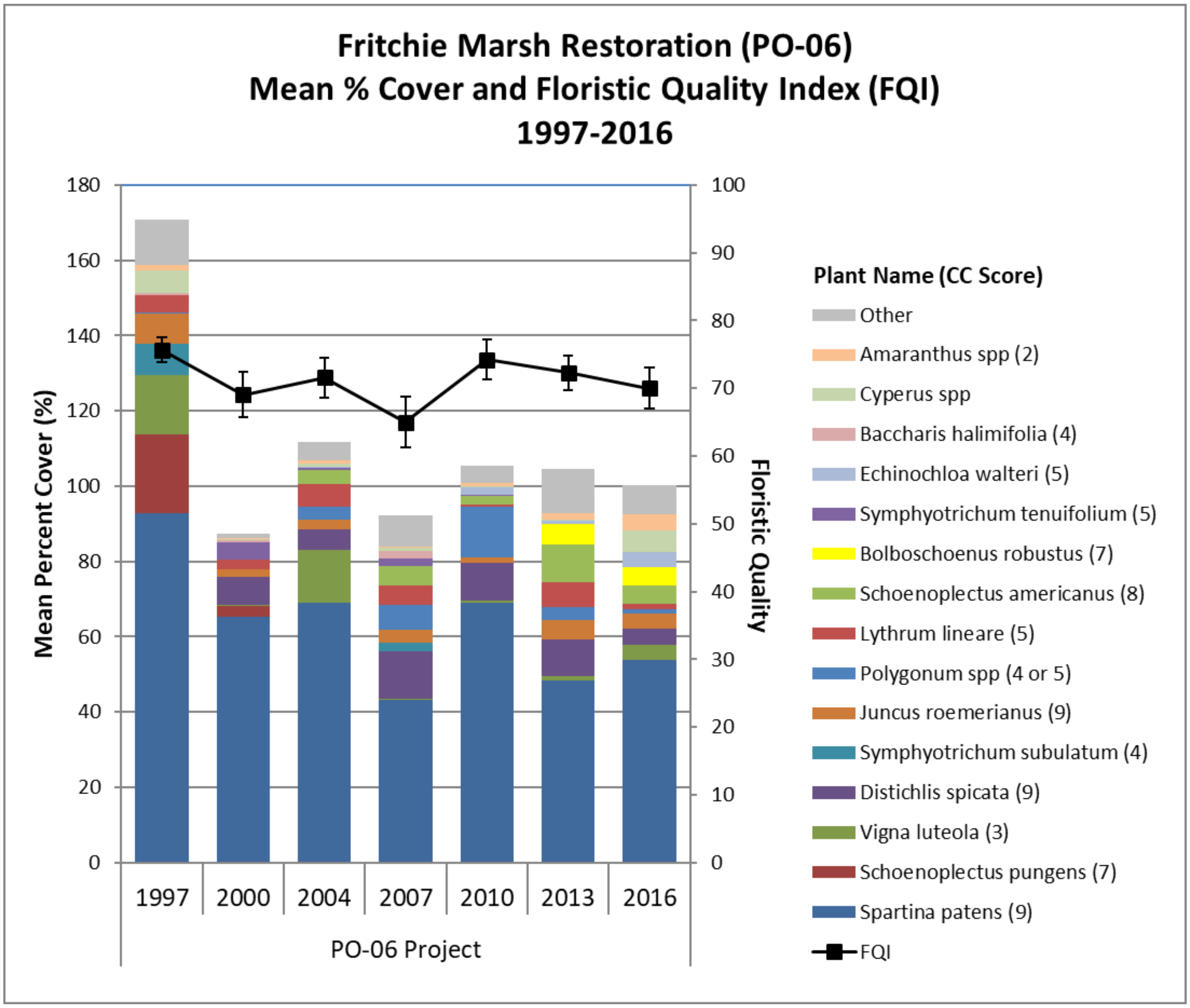


Figure 16. Mean percent cover of species within the PO-06 project area and the Floristic Quality Index (FQI) score for each sample year from 1997 to 2016. The CC score represents the quality of the individual species on a scale from 1 to 10 where 1 represents disturbance species and 10 indicates species found in stable environments.

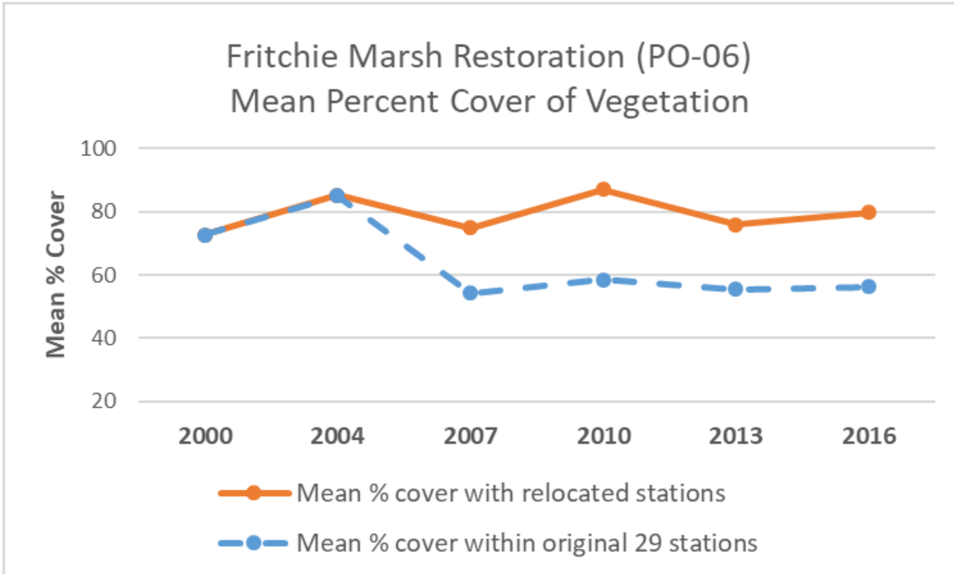


Figure 17. Total mean % cover of vegetation within the PO-06 project area (n=29 stations) when calculated with relocated stations (n=9) vs. all original stations.

Table 3. The percent occurrence of species found within all vegetation plots (n=29) during seven sampling events of the PO-06 project area from 1997 to 2016.

Scientific Name	Common Name	% Occurrence Within Total Plots (n=29)						
		1997	2000	2004	2007	2010	2013	2016
Alternanthera philoxeroides	alligatorweed		*	3		*	*	14
Amaranthus spp	pigweed	20	17	14	17	24	17	24
Ammannia spp	redstem	16		24	10	7	3	14
Andropogon glomeratus	bushy bluestem	*						
Baccharis halimifolia	eastern baccharis	4	14		10	*	*	*
Bacopa monnieri	herb of grace	4	21		7	3		
Boehmeria cylindrica	smallspike false nettle			3				
Bolboschoenus robustus	sturdy bulrush	*			3	14	24	17
Cuscuta spp	dodder					7	7	*
Cyperus odoratus	fragrant flatsedge	40		17	10	17	3	45
Cyperus spp	flatsedge	20	3	10	7	17		
Distichlis spicata	saltgrass	*	48	34	41	34	55	45
Echinochloa spp	cockspur grass					3	7	
Echinochloa walteri	coast cockspur grass	8		21	7	24	3	24
Eclipta prostrata	false daisy	8						
Eleocharis cellulosa	Gulf Coast spikerush	8		10	3	3		
Eleocharis spp	spikerush	4	3	17				*
Fimbristylis castanea	marsh fimbry			*				
Galium tinctorium	stiff marsh bedstraw			21				
Hydrocotyle spp	hydrocotyle	*		7				
Ipomoea sagittata	saltmarsh morning-glory	24	24	10	10	17	17	3
Iva frutescens	Jesuit's bark	4	10	*	31	14	10	7
Juncus roemerianus	needlegrass rush	24	21	14	14	21	14	17
Kosteletzkya virginica	Virginia saltmarsh mallow	8	*	*	*			
Leptochloa fusca	Malabar sprangletop				*	7		
Ludwigia spp	primrose-willow	4		3				7
Lythrum lineare	wand lythrum	44	31	59	76	24	55	28
Panicum dichotomiflorum	fall panicgrass	*						
Panicum repens	torpedo grass	8				3		
Paspalum vaginatum	seashore paspalum				3	3		
Pennisetum glaucum	pearl millet			*				
Phragmites australis	common reed	4	*					*
Pluchea spp	camphorweed	12	7	14	3	10	3	17
Polygonum spp	knotweed	4		34	24	59	21	10
Sabatia spp	rose gentian			*		3		
Sacciolepis striata	American cupscale				*			
Sagittaria lancifolia	bulltongue arrowhead	4		3		*	*	3
Schoenoplectus americanus	chairmaker's bulrush			28	41	28	41	28
Schoenoplectus pungens	common threesquare	44	21					
Sesbania herbacea	bigpod sesbania	*				3	*	*
Setaria magna	giant bristlegrass	*						
Setaria parviflora	marsh bristlegrass				3			
Setaria pumila	yellow foxtail	*	*		*	*		
Solidago sempervirens	seaside goldenrod	*	*					
Spartina alterniflora	smooth cordgrass		*					
Spartina cynosuroides	big cordgrass				3			
Spartina patens	saltmeadow cordgrass	100	100	100	97	97	97	90
Symphyotrichum divaricatum	southern annual saltmarsh aster						3	*
Symphyotrichum spp	aster						10	
Symphyotrichum subulatum	eastern annual saltmarsh aster	36			10	3		
Symphyotrichum tenuifolium	perrenial saltmarsh aster		45	17	24	14		
Typha spp	cattail				*			*
Vigna luteola	hairypod cowpea	52	17	45	17	24	21	41
	Total # of species:	**34**	**21**	**28**	**29**	**31**	**23**	**25**
***Species observed within 15-ft outside of the vegetation plots.**								

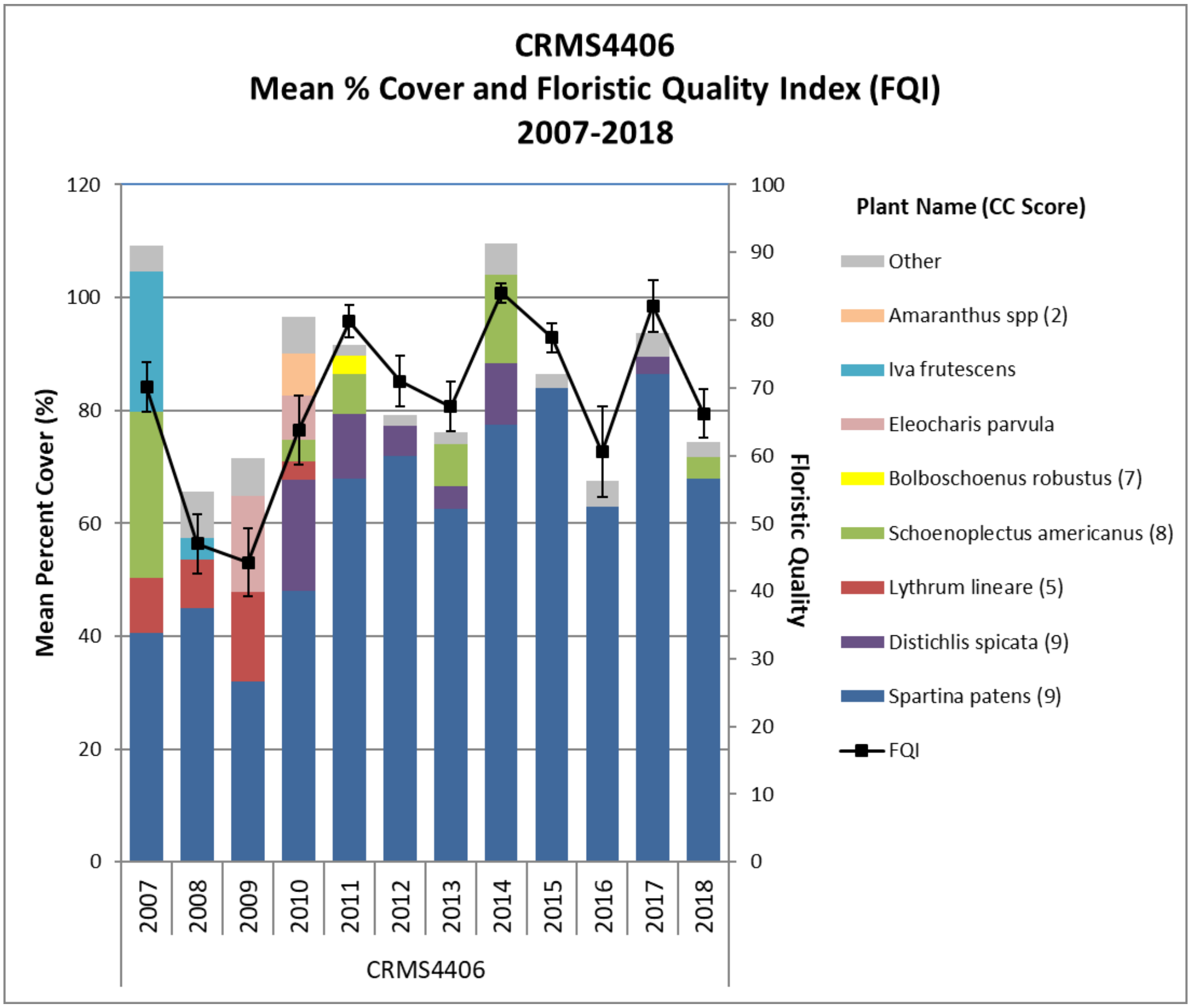


Figure 18. Mean % cover of major species and FQI score at CRMS4406 from 2007 to 2018.

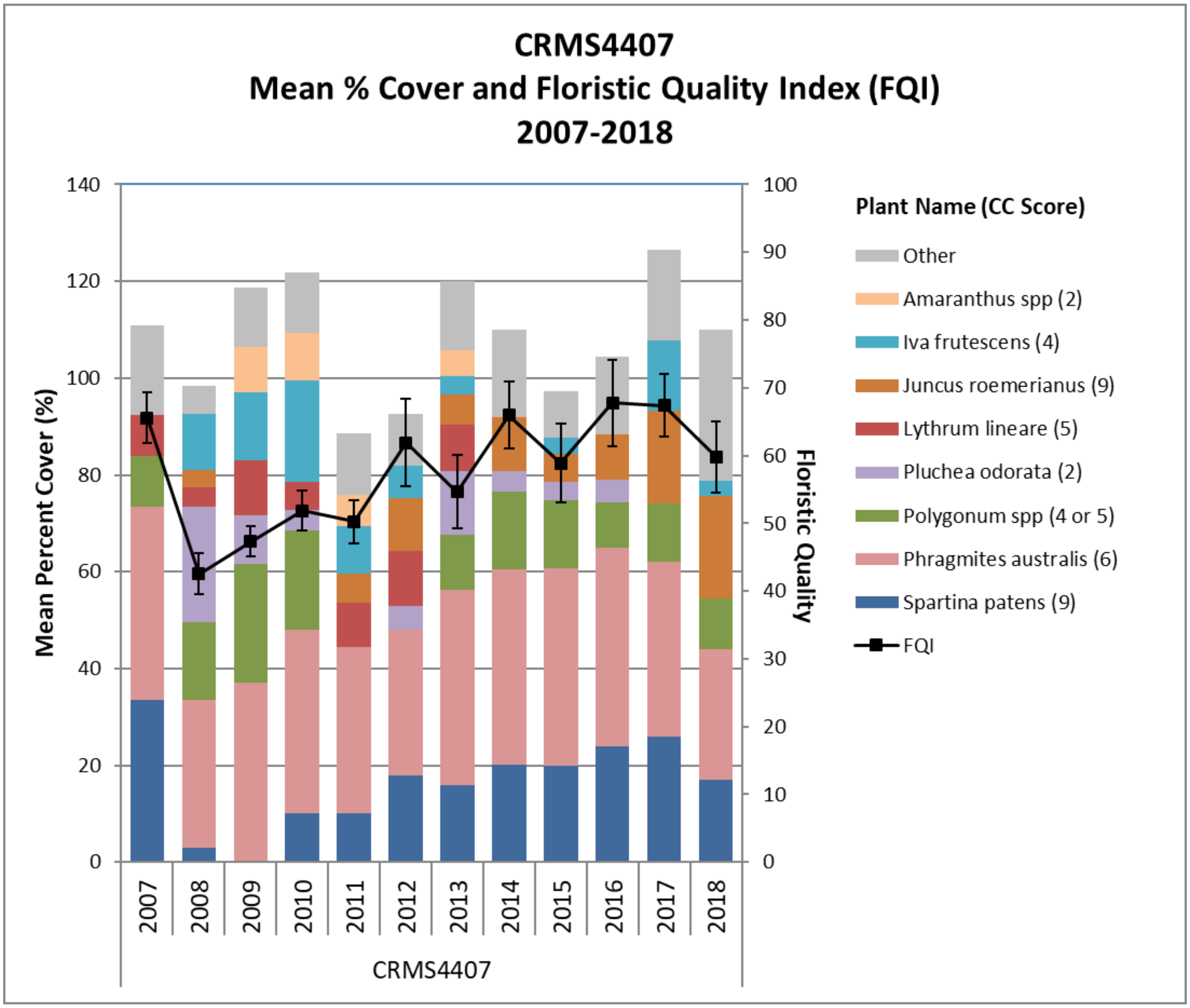


Figure 19. Mean % cover of major species and FQI score at CRMS4407 from 2007 to 2018.

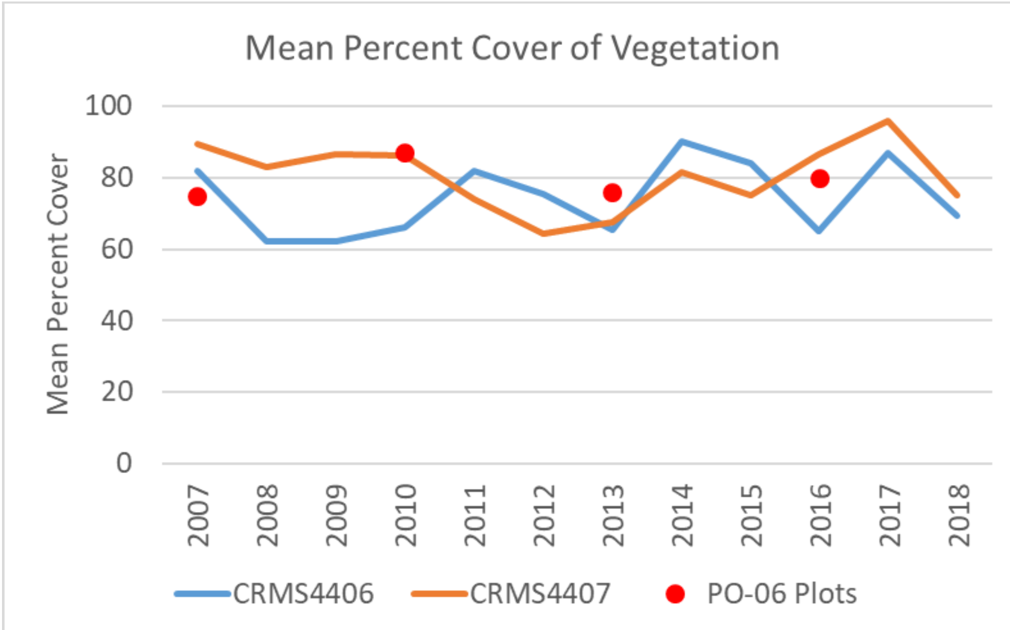


Figure 20. Mean % cover of vegetation at CRMS4406, CRMS4407, and the PO-06 plots from 2007 to 2018.

One tool that has been used to assess the quality of the vegetation community at the CRMS sites is the Floristic Quality Index (FQI) (Cretini et al. 2011). The FQI is calculated by assigning each species a CC score, or coefficient of conservatism, which is scaled from 1 to 10 and reflects a species' tolerance to disturbance and habitat specificity. A modified FQI was developed by the CRMS Vegetation Analytical Team, which assembled a team of experts to assign CC scores to Louisiana's wetland plant species. The modified FQI equation takes into account not only the CC scores, but also the percent covers of species at a site, and the resulting score is scaled from 0 to 100. Mean FQI scores were calculated for the PO-06 project sites and CRMS sites for each of the sampling years (Figures 16, 18, and 19). FQI scores over the life of the PO-06 project (Figure 16) were relatively stable and generally mirrored fluctuations in percent cover of *S. patens,* which is assigned a high CC score of 9. FQI scores ranged from 65 to 76, which is just below the ideal range of 80-100 for intermediate/brackish marsh, as estimated by the CRMS Vegetation Analytical Team (Cretini et al. 2011). The FQI score at CRMS4406 dropped below 50 in 2008 and 2009, but since then has fluctuated between 61 and 84. FQI scores were lower at CRMS4407, ranging from 43 to 68, due to the higher abundance of fresh/intermediate species, which are often associated with disturbance and therefore have lower CC scores. There has been a steady increase in the FQI score at CRMS4407 from 2008 to 2018 which mirrors the increase in *S. patens* observed at the site.

The main goal of the Fritchie Marsh Restoration project was to increase the flow of fresh water into the project area. The decrease in salinity observed within the project area (Figure 12) may be reflected within the vegetation community through a transition from brackish to a more fresh/intermediate community type. In order to detect transitions in marsh type within the project area, marsh types were automatically generated by species composition and cover data for all individual sample plots. Marsh types were calculated through an algorithm described in Visser et al. 2002, in which each species present is assigned a salinity score based on the marsh type in which it is most commonly found. The percentage of plots for each sample year that were characterized as fresh/intermediate was then calculated to determine trends in this community type over time. It does not appear that the decrease in salinity has induced a shift to a more fresh/intermediate community type. Contrarily, there was a decreasing trend (r^2=0.437) in the percentage of fresh/intermediate plots over time for the PO-06 sample years (Figure 21), with the percentage of fresh/intermediate plots dropping from 90% in 1997 to 41% in 2016. The most significant change occurred between 1997 and 2000 (pre-construction) following the extreme drought, with a change from 90% to 45% fresh/intermediate plots; however, the downward trend persists with the pre-construction years removed (r^2=0.423). The two CRMS sites also displayed a trend toward a more brackish community from 2007 to 2018 (Figure 22) and provide further insight regarding localized differences in vegetation within the project area. The trend at CRMS4407 (r^2=0.433), which is located in the northern project area and contains a more diverse assemblage of fresh/intermediate species, was similar to the PO-06 site trend, while the trend was much weaker at CRMS4406 (r^2=0.022), which is a more stable, monotypic *S. patens* marsh; therefore, the trend toward a less fresh/intermediate community may be driven by changes within the northern project area which is displaying an increase in *S. patens* over time. Transition in marsh type is not a direct indicator of project success, but can merely demonstrate whether increased freshwater input is inducing changes within the community structure. Many additional stressors also impact the vegetation community, such as drought and hurricanes, which can counteract project effects. It is possible that the project features may have dampened the impacts of stressors such as drought and hurricanes, which may have caused an even greater shift toward a brackish/saline community.

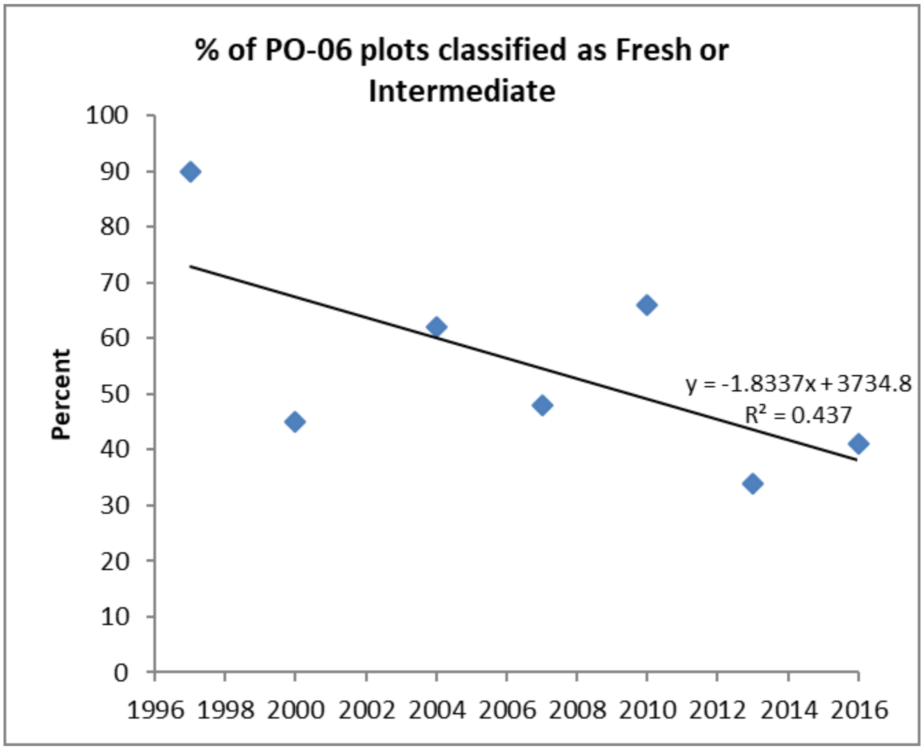


Figure 21. Percentage of PO-06 vegetation plots classified as fresh/intermediate from 1997 to 2016.

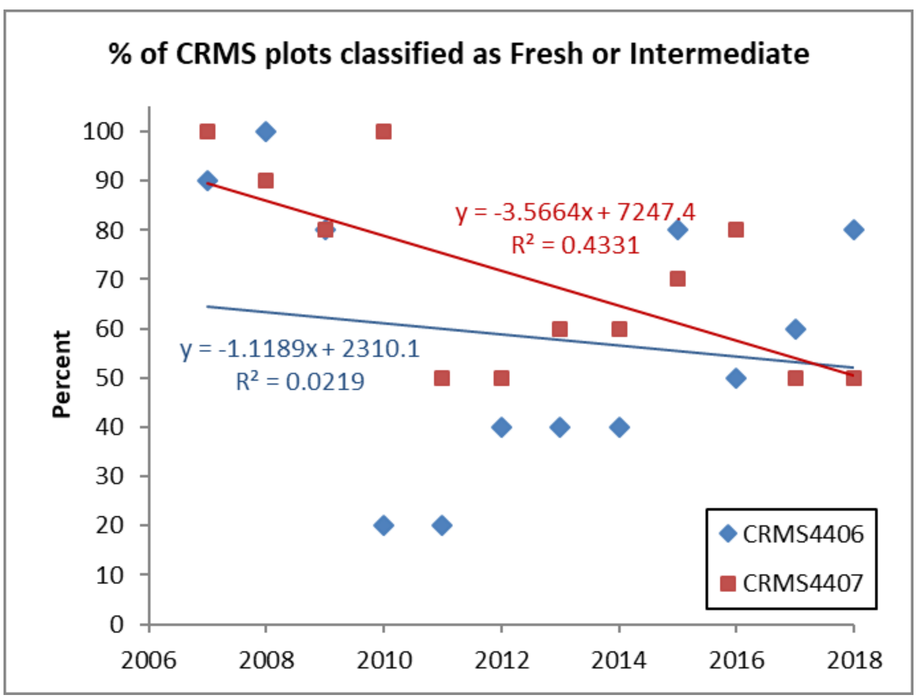


Figure 22. Percentage of CRMS vegetation plots within the Fritchie Marsh Restoration (PO-06) project area classified as fresh/intermediate from 2007 to 2018.

V. Conclusions

a. Project Effectiveness

Although the constructed project features appeared to have a significant effect on the hydrology of Fritchie Marsh, the effectiveness of the project was confounded by the extreme impacts of Hurricane Katrina. The primary objective of the Fritchie Marsh Restoration project was to reduce marsh loss by restoring more natural hydrologic conditions in the project area through management of available freshwater. Assumptions were made during the WVA planning process that the constructed project would reduce land loss rates by 75%. Only four years after construction, however, the passage of Hurricane Katrina contributed to a significant land loss of 916 acres during the 2004-2010 period. Small gains in land acreage, however, were observed in the periods immediately before (+3 ac/yr) and after Hurricane Katrina (+18 ac/yr). The resulting overall land loss rate observed within the project area through Year 16 of the project life was -50 ac/yr. This land loss rate is lower than the historic WVA land loss rate (-69 ac/yr) but greater than the land loss rate observed immediately pre-construction (-32 ac/yr). Land gains during the non-Katrina periods indicate that the project may have been having a positive effect; however, a decrease in the loss rate was also observed within the reference area during these periods. Although the land acreage is currently below the 'Future With Project' projections due to the hurricane-induced losses, the land acreage at Year 16 (2016) is 310 acres higher than the 'Future Without Project' projected acreage at Year 16. It is possible that the hydrologic modifications associated with the project may have provided some protective benefit through enhanced resiliency to the impacts of the storm.

The constructed features of the Fritchie Marsh Restoration Project appeared to be having the desired effect on the hydrology of Fritchie Marsh through the end of the project-specific monitoring period in June 2005. Mean salinity was lower and mean water level was higher during the post-construction period, suggesting increased flow of freshwater into the project area. Although this response would be expected following the extreme drought which occurred just before construction, a project effect was detected for both salinity and water level even with the drought period removed. Following Hurricane Katrina, existing breaches on the banks of Salt Bayou were enlarged and new breaches were created, which are now diverting water away from the natural conveyance channels. Although siltation and floating vegetation within Salt Bayou has been a concern, fresh water from the Hwy 90 culvert still appears to be entering the main project area through several breaches along Salt Bayou nearer to the culvert; therefore, the goal of bringing fresh water into the project area is still being achieved. Following Hurricane Katrina, there was a weak trend of decreasing salinity and increasing water levels during the CRMS data collection period (2007-2018). Although increased inundation has been shown to reduce productivity within *S. patens* marshes (Snedden et al. 2015), a positive surface elevation change rate measured at both CRMS sites should provide some resiliency to increased inundation within the project area.

There was a shift in the vegetation community from fresh/intermediate to a more brackish community immediately before project construction due to the extreme drought. For the duration of the project life, the vegetation community has remained relatively stable based on the Floristic Quality Index values and observed mean percent vegetative cover over time. The marsh type can be classified as intermediate to brackish and continues to be dominated by *Spartina patens*. Data indicated a weak trend toward a less fresh/intermediate marsh type in the northern project area, which is contrary to the observed decrease in salinity during the CRMS period. Climatological events, such as drought and storms, appear to be having a greater influence on the vegetation community structure than the project features.

b. End of Life Recommendations

The 20-year life of the Fritchie Marsh Restoration project ends in March 2021. The Project Sponsors (NRCS and CPRA) agree that there is no justification to request a project life extension. The CPRA has been in discussion with the Louisiana Department of Transportation and Development (DOTD) regarding transfer of ownership of the culvert under Hwy 90 to the DOTD at the end of the project life. The DOTD has requested that the last joint of the culvert on the west side of the highway, which has settled and shows some separation, be removed and replaced with armoring to dress the slope and minimize future erosion. The DOTD has advised that a transfer agreement would not be needed for this culvert because any structure under a state highway would be DOTD property by default.

A potential transfer of the weir in the W-14 Canal has been discussed with both St. Tammany Parish and the USFWS. Both of these entities would prefer for the structure to be left in place, but do not want to formally accept ownership of the weir. At this time the Project Sponsors will maintain ownership of this structure, but conversations are ongoing with the landowner and the St. Tammany Parish Government concerning structure turnover.

The condition of Salt Bayou has changed significantly during the life of this project as a result of Hurricane Katrina. There are no plans to re-establish Salt Bayou to the condition it was in prior to Hurricane Katrina as part of the PO-06 project; however, St. Tammany Parish is currently considering future restoration efforts within Fritchie Marsh, including restoring Salt Bayou and its historic banklines. The elements of this plan will depend on future funding availability.

The Project Sponsors propose to perform a final maintenance event (remove the last joint of the culvert on the west side of the highway and dress the slope to minimize future erosion). It is anticipated that no additional funding would be required. Upon completion of this maintenance event, and balancing of budget, project sponsors propose project closeout with no feature removal. The positive impacts of leaving the features in place is that: 1) the project will continue to function, and 2) there will be no additional costs for structure removal. Negative impacts of leaving the features in place are: 1) the weir poses a medium risk to navigation along the W-14 Canal, 2) the culvert poses a low risk to vehicular traffic, and 3) future maintenance of the weir may be required.

c. Lessons Learned

Monitoring activities are inherently linked to project feature construction. Construction delays can often result in the need to repeat pre-construction monitoring data collection due to changes in site conditions when construction is delayed. Because of construction delays of the Fritchie Marsh Restoration Project, an extra round of pre-construction habitat analysis and vegetation monitoring was conducted in the year 2000, which was an unanticipated cost.

Climatic anomalies, such as drought, may confound hydrologic data results, especially in cases where a reference area was not monitored. In this case, however, a suitable reference area for hydrologic monitoring did not exist. The Coastwide Reference Monitoring System (CRMS) now provides valuable pre/post-construction reference data for more recently constructed projects.

Extreme weather events, such as droughts and hurricanes, create additional challenges in the maintenance and monitoring of coastal restoration projects. In this case, Hurricane Katrina altered the hydrology of the project area and caused significant marsh loss. In the wake of such events, adaptive decision-making is important when determining whether original project features should be maintained (i.e, Salt Bayou dredging). Additionally, the effects of project features can be difficult to distinguish amid extreme storm impacts such as Hurricane Katrina.

Future restoration efforts for the Fritchie Marsh are currently being developed by the St. Tammany Parish Government, which must incorporate the effects of multiple projects currently in the design or construction phase. A hydrodynamic modeling study of the Fritchie Marsh was conducted to evaluate the impacts of drainage improvements and proposed marsh and bottomland hardwood creation projects on predicted flood elevations upstream of Fritchie Marsh (Wang et al. 2018). While all hydrologic restoration projects should conduct hydrologic modeling to determine project effectiveness, it would also be pertinent to model for future restoration or public works projects as a part of that effort. Many areas require large-scale restoration involving multiple restoration techniques, but due to limited funding only partial restoration may be implemented. The overall restoration needs of an area should be considered when planning and designing restoration projects and how those needs may change as more restoration is funded.

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Appendix A
(Budget Projection)

Fritchie Marsh Hydrologic Restoration (PO-06)
Federal Sponsor: NRCS
Construction Completed : March 6, 2001
PPL 2

Current Approved O&M Budget June 2009	Year 0 FY02	Year - 1 FY03	Year -2 FY04	Year -3 FY05	Year -4 FY06	Year -5 FY07	Year -6 FY08	Year -7 FY09	Year -8 FY10	Year -9 FY11	Year -10 FY12	Year -11 FY13	Year -12 FY14	Year -13 FY15	Year -14 FY16	Year -15 FY17	Year -16 FY18	Year - 17 FY19	Year -18 FY20	Year -19 FY21	Project Life Budget
State O&M																					$225,211
Corps Admin																					$0
Federal S&A																					$0
Total																					$225,211

Projected O&M Expenditures																					Remaining Project Life
Maintenance Inspection																	$4,428	$4,543	$4,661	$4,782	$9,444
General Maintenance																				$7,500	$7,500
Surveys																					$0
Sign Replacement																					$0
Federal S&A																					$0
Maintenance/Rehabilitation																					$0
E&D																				$5,000	$5,000
Construction																				$35,000	$35,000
Construction Oversight																				$2,500	$2,500
Total																	$4,428	$4,543	$4,661	$54,782	$59,444

O&M Expenditures from COE Lana Report (2-2019)	$151,886
State O&M Expenditures not submitted for in-kind credit	$0
Federal Sponsor MIPRs (if applicable)	$0
Total Estimated O&M Expenditures (as of October 2017)	$151,886

Current O&M Budget	$225,211
Estimated O&M Expenditures	$151,886
Remaining Available O&M Budget	**$73,325**

Current Project Life Budget	$225,211
Total Projected Project Life Budget	$211,330
Project Life Budget Surplus (Shortfall)	**$13,881**

Appendix B
(Field Inspection Notes)

MAINTENANCE INSPECTION REPORT CHECK SHEET

Project No. / Name: **PO-06 Fritchie Marsh**

Date of Inspection: 11/08/2017 Time: 10:00am

Structure No. n/a

Inspector(s): Worley (CPRA), Richard (CPRA), Baker (NRCS),

Structure Description: **HWY 90 Culvert; Salt Bayou Dredging; W-14 Canal Weir Structure; W-14 Canal Diversion Channel**

Water Level Inside: n/a Outside: n/a

Type of Inspection: **Annual**

Weather Conditions: Cool, cloudy

Item	Condition	Physical Damage	Corrosion	Photo #	Observations and Remarks
W-14 Weir Handrails, Hardware, etc.	Good	None	None	4	No significant defects noted.
W-14 Weir Signage, Supports	Very Good	None	None	4	Signs and timber support piles appeared to be in very good condition.
Hwy 90 Culvert Riprap Lining	Good	None		1	Good condition. Rip-rap covered by concrete debris on South bank.
W-14 Weir structure	See remarks	See remarks		4	Structure was mostly hidden by emergent vegetation; strong flow was visible in channel.
W-14 diversion channel dredge	Fair	None		5	Channel entrance is filled in and unnavigable due to aquatic vegetation. Emergent vegetation was present in outfall.
Salt Bayou dredging	See remarks	N/A		3	Salt Bayou was deep and unobstructed for about 4,500 feet downstream (marsh side) of culverts at US Hwy 90. Siltation was noted beginning at approx. Sta. 45+00 and continued southwest to Sta. 53+00.
72" Diameter culvert	Fair	None		1,2	Appeared to be some seperation at joint on the west side of Hwy 90; water appeared to be flowing freely through culvert.
HWY 90 road surface	Good	None			No significant change since last inspection.

Appendix C
(Inspection Photographs)

Photo 1: Culverts Beneath Hwy. 90 (West Side)

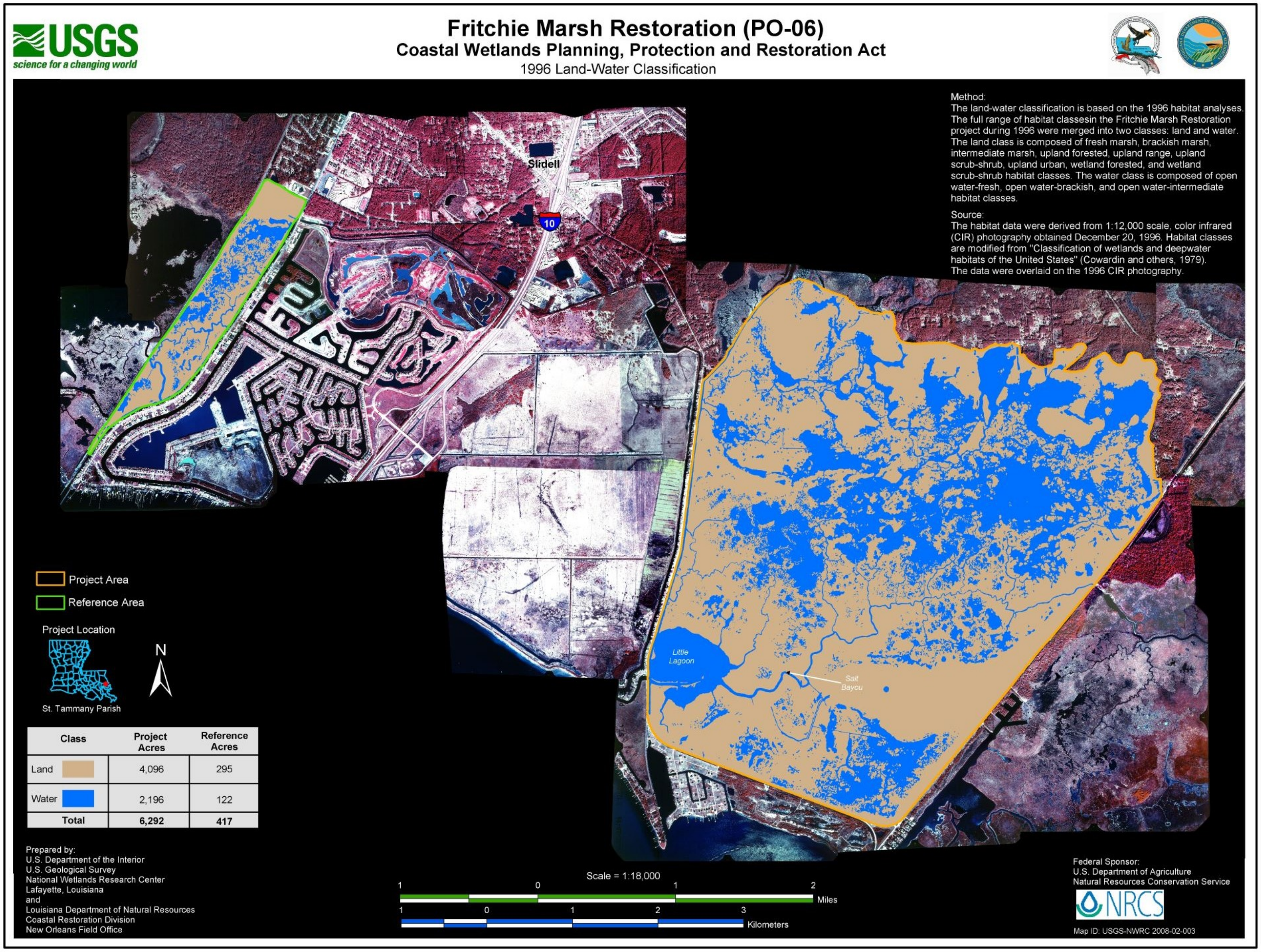
Photo 2: Joint Separation of Hwy 90 Culvert (West Side)

Photo 3: Salt Bayou Flowing West into Project Area (West Side of Hwy 90)

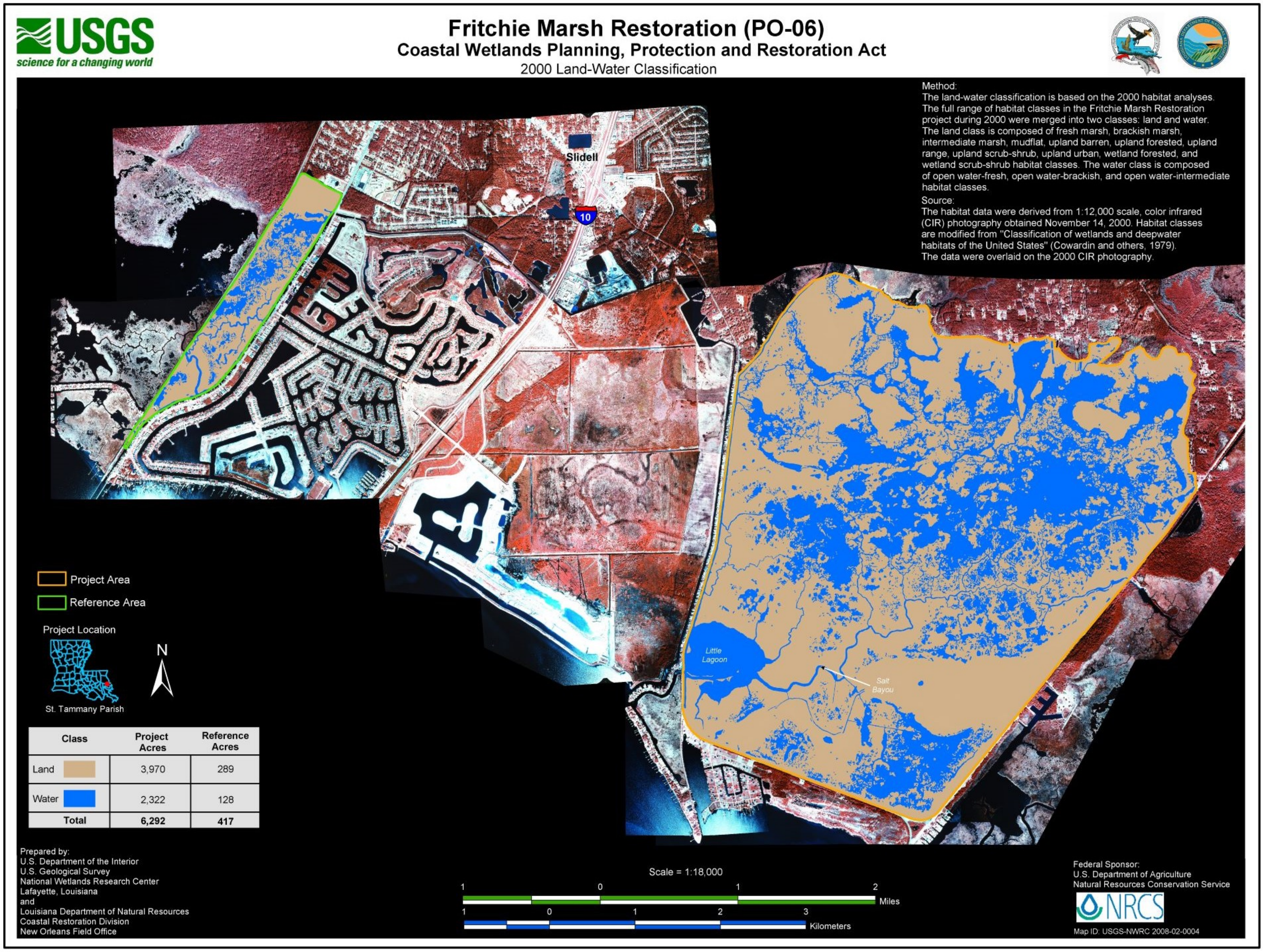
Photo 4: W-14 Canal Weir with Handrails and Warning Signs

Photo 5: W-14 Diversion Channel Entrance looking from the W-14 Canal

Appendix D
(Land-Water Analyses)

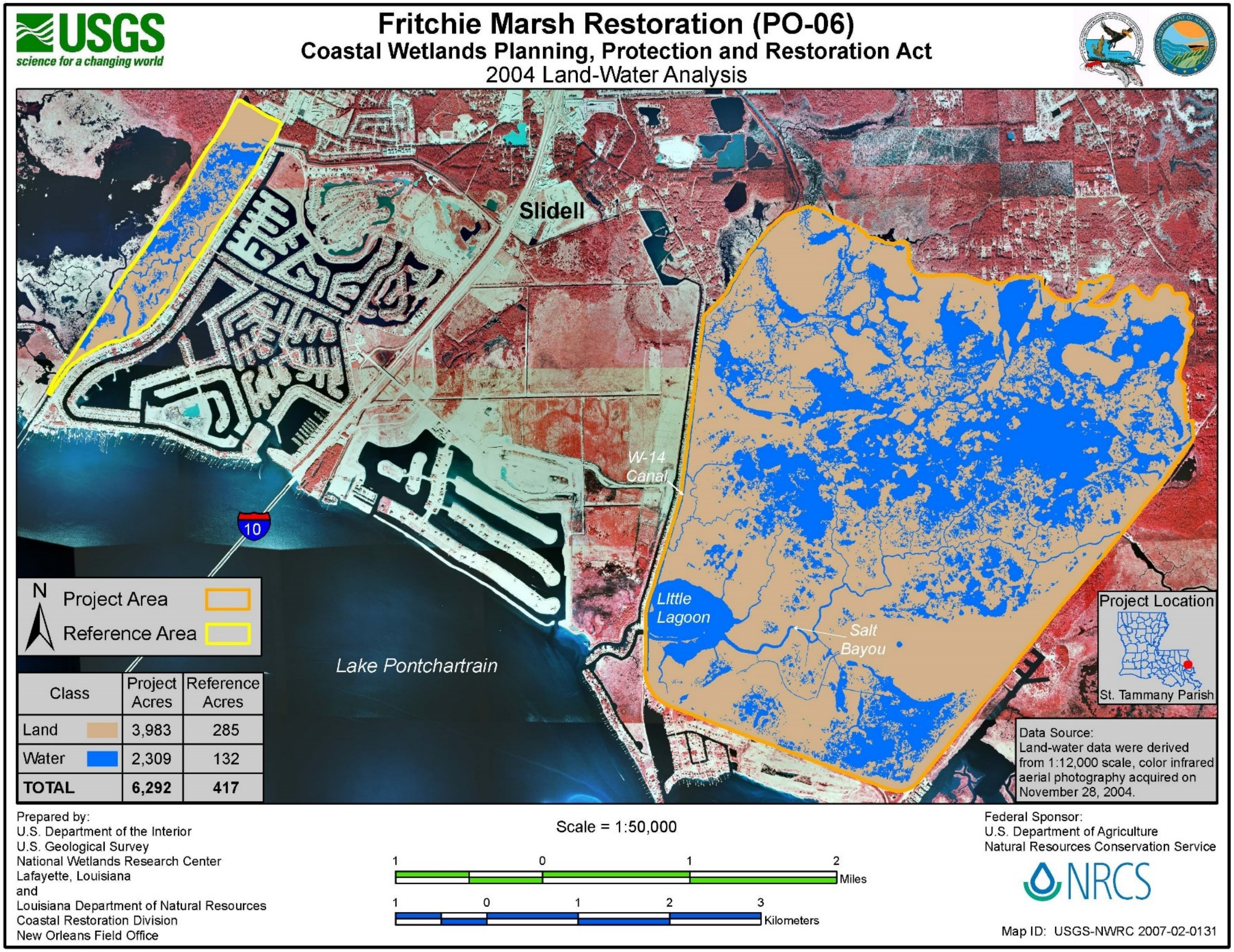


Appendix D1. 1996 land-water classification of the Fritchie Marsh Restoration (PO-06) project and reference areas.



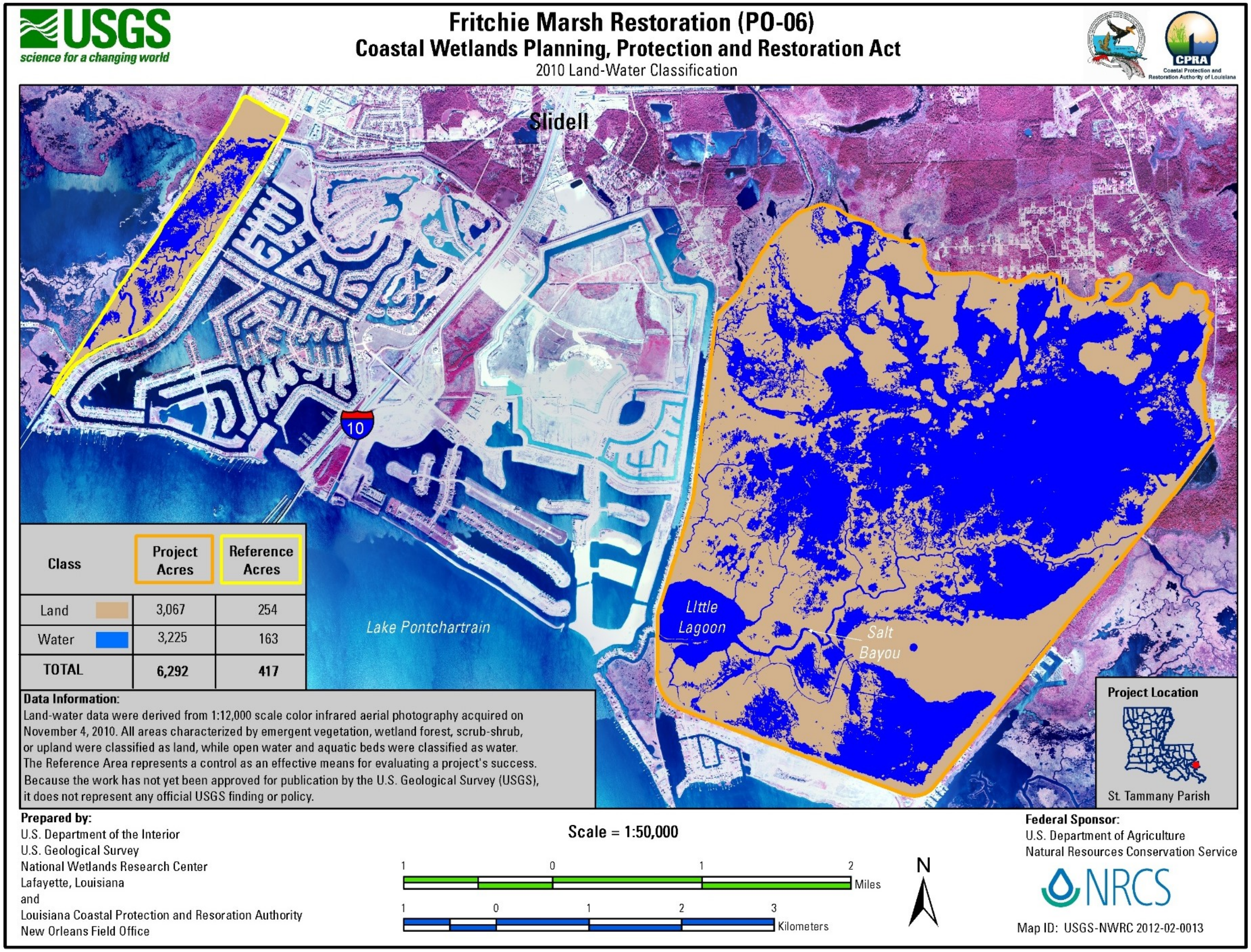
Class	Project Acres	Reference Acres
Land	3,970	289
Water	2,322	128
Total	6,292	417

Appendix D2. 2000 land-water classification of the Fritchie Marsh Restoration (PO-06) project and reference areas.



Class	Project Acres	Reference Acres
Land	3,983	285
Water	2,309	132
TOTAL	**6,292**	**417**

Appendix D3. 2004 land-water classification of the Fritchie Marsh Restoration (PO-06) project and reference areas.

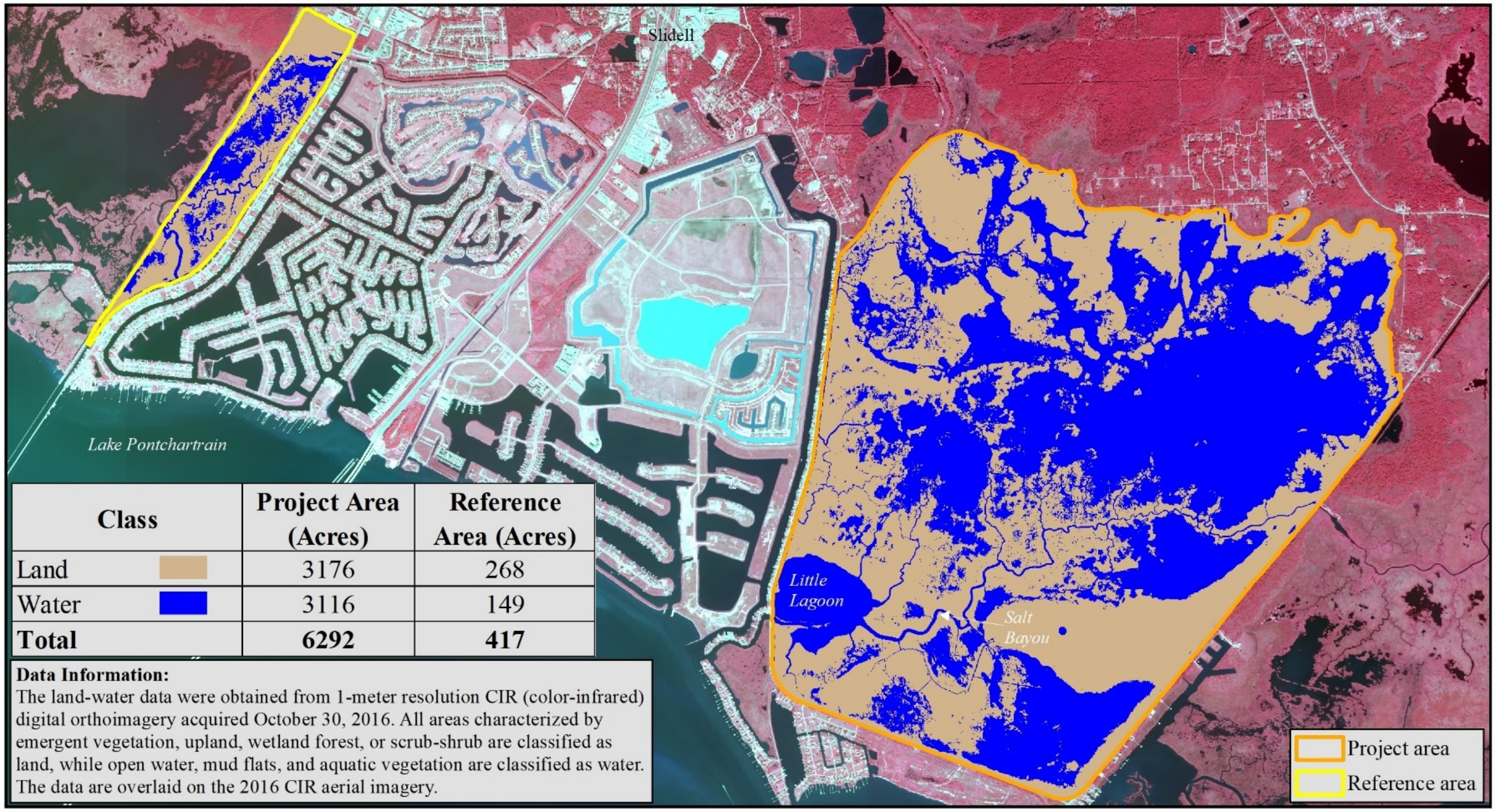


Appendix D4. 2010 land-water classification of the Fritchie Marsh Restoration (PO-06) project and reference areas.

Fritchie Marsh Restoration (PO-06)

Coastal Wetlands Planning, Protection and Restoration Act

2016 Land-Water Classification

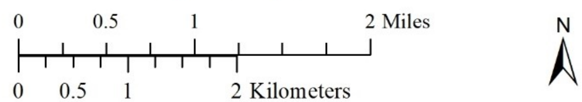


Class	Project Area (Acres)	Reference Area (Acres)
Land	3176	268
Water	3116	149
Total	**6292**	**417**

Data Information:
The land-water data were obtained from 1-meter resolution CIR (color-infrared) digital orthoimagery acquired October 30, 2016. All areas characterized by emergent vegetation, upland, wetland forest, or scrub-shrub are classified as land, while open water, mud flats, and aquatic vegetation are classified as water. The data are overlaid on the 2016 CIR aerial imagery.

Prepared by:
U.S. Department of the Interior
U.S. Geological Survey
Wetland and Aquatic Research Center
Lafayette, LA and
Coastal Protection and Restoration Authority of Louisiana
New Orleans Regional Office
Federal Sponsor: Natural Resources Conservation Service

Scale = 1:53,000



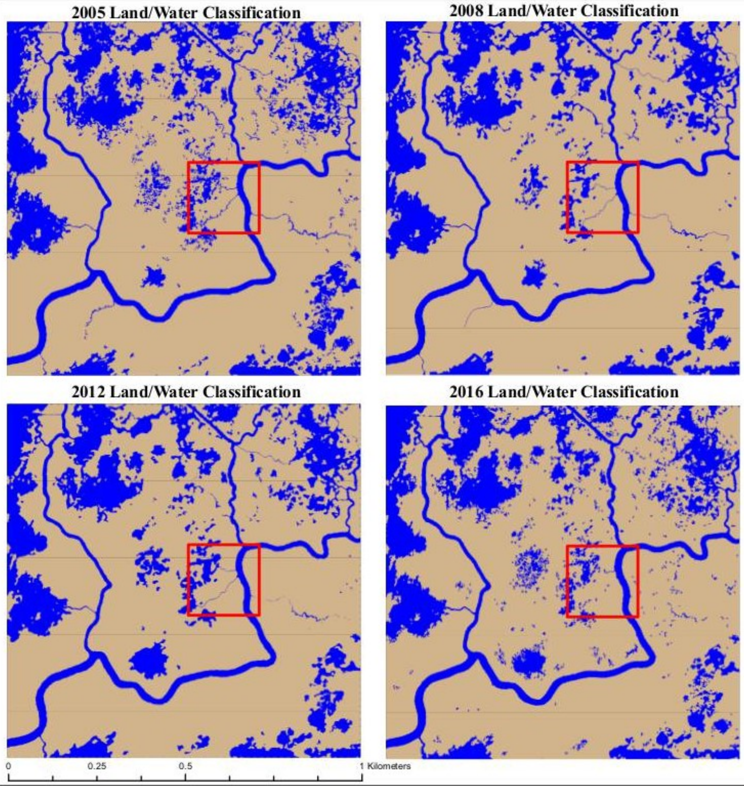
DOI: 10.5066/P913JO74

Appendix D5. 2016 land-water classification of the Fritchie Marsh Restoration (PO-06) project and reference areas.

CRMS Site 4406

Coastwide Reference Monitoring System (CRMS)

2005, 2008, 2012, and 2016 Land/Water Classifications and Matrix



Background:
The analysis presented here is part of a program which monitors land area change using fine-spatial scale aerial imagery approximately every three years at Coastwide Reference Monitoring System (CRMS) sites. This site is one of 390 sites that encompass the range of ecological conditions in coastal Louisiana.

Data Information:
Refer to individual data products for information regarding each year of data. All areas characterized by emergent vegetation, upland, wetland forest, or scrub-shrub were classified as land, while open water, aquatic beds, and mudflats were classified as water.

Land/Water Classification Legend (Individual Years)

Land

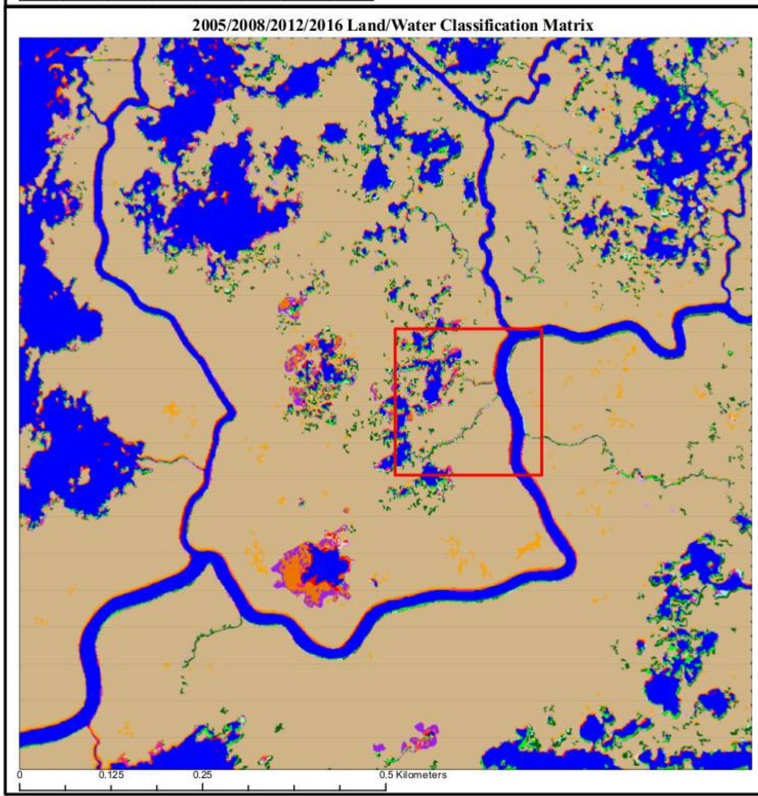
Water

Data Collection Area (DCA)*

*Field collection of ecologic and hydrologic parameters occur within the DCA.

CRMS Site 4406			
	Land (Acres)	Water (Acres)	Total (Acres)
2005	187.7	59.4	247.1
2008	190.3	56.8	247.1
2012	187.4	59.7	247.1
2016	187.6	59.5	247.1

Matrix Information:
The matrix is provided for coarse scale observations. Errors in georectification can contribute to fine-scale differences among years. Please refer to product metadata for more information on appropriate uses for the data and its interpretation.



CRMS Site 4406			
Color	Class Description	% of Area	Acres
	Out	0.08%	0.21
	Persistent land	69.94 %	172.83
	Ephemeral water-2008	0.50%	1.24
	Ephemeral water-2012	0.69%	1.71
	Land-water-water-land	0.53%	1.30
	Land-water-land-water	0.09%	0.23
	New water-2016	2.00%	4.95
	Persistent loss-2012	1.05%	2.59
	Persistent loss-2008	1.09%	2.70
	Persistent gain-2008	1.85%	4.56
	Persistent gain-2012	0.55%	1.36
	New land-2016	1.56%	3.85
	Water-land-water-land	0.27%	0.67
	Water-land-land-water	0.60%	1.48
	Ephemeral land-2012	0.22%	0.54
	Ephemeral land-2008	0.54%	1.33
	Persistent water	18.44 %	45.56
	Total	100.00 %	247.11

Project Location

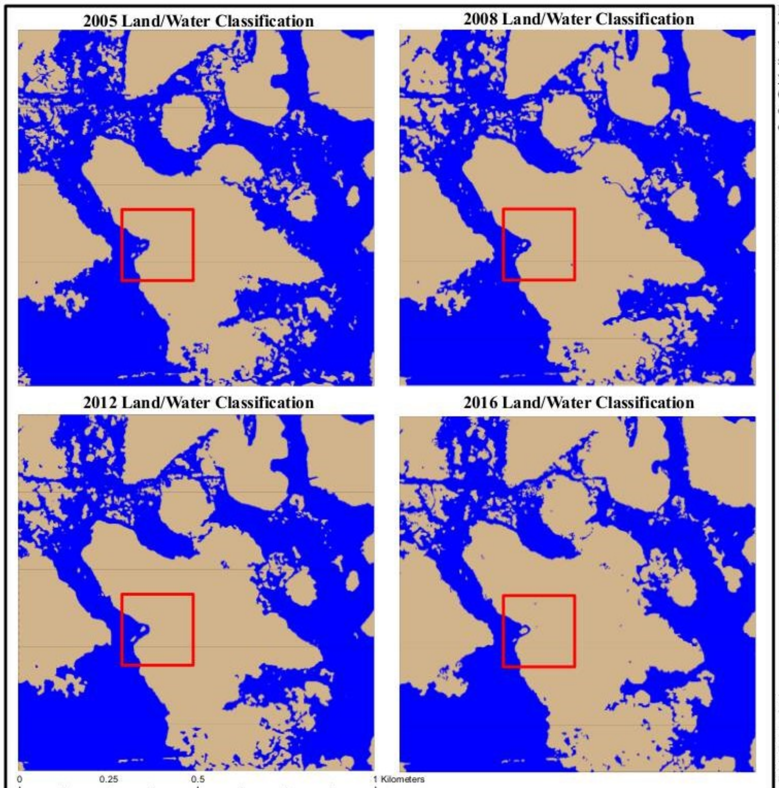
Prepared by:
U.S. Department of the Interior
U.S. Geological Survey
Wetland and Aquatic Research Center
Baton Rouge, Louisiana
Prepared for:
Louisiana Coastal Protection and Restoration Authority
New Orleans Field Office
DOI: 10.5066/P91BNNS0

Appendix D6. 2005, 2008, 2012, and 2016 Land/Water Classifications and Matrix for CRMS4406.

CRMS Site 4407

Coastwide Reference Monitoring System (CRMS)

2005, 2008, 2012, and 2016 Land/Water Classifications and Matrix



Background:
The analysis presented here is part of a program which monitors land area change using fine-spatial scale aerial imagery approximately every three years at Coastwide Reference Monitoring System (CRMS) sites. This site is one of 390 sites that encompass the range of ecological conditions in coastal Louisiana.

Data Information:
Refer to individual data products for information regarding each year of data. All areas characterized by emergent vegetation, upland, wetland forest, or scrub-shrub were classified as land, while open water, aquatic beds, and mudflats were classified as water.

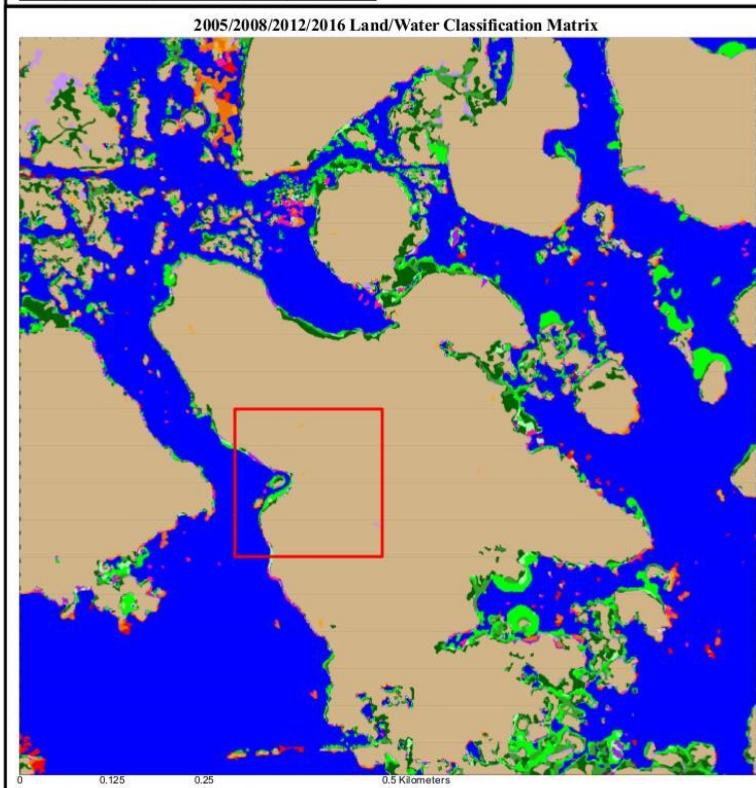
Land/Water Classification Legend (Individual Years)

- Land
- Water
- Data Collection Area (DCA)*

*Field collection of ecologic and hydrologic parameters occur within the DCA.

CRMS Site 4407			
	Land (Acres)	Water (Acres)	Total (Acres)
2005	124.4	122.7	247.1
2008	132.9	114.2	247.1
2012	133.7	113.4	247.1
2016	141.5	105.6	247.1

Matrix Information:
The matrix is provided for coarse scale observations. Errors in georectification can contribute to fine-scale differences among years. Please refer to product metadata for more information on appropriate uses for the data and its interpretation.



CRMS Site 4407			
Color	Class Description	% of Area	Acres
	Out	0.04%	0.11
	Persistent land	47.93 %	118.44
	Ephemeral water-2008	0.44%	1.08
	Ephemeral water-2012	0.37%	0.91
	Land-water-water-land	0.11 %	0.28
	Land-water-land-water	0.03%	0.07
	New water-2016	0.42%	1.04
	Persistent loss-2012	0.63%	1.55
	Persistent loss-2008	0.38%	0.94
	Persistent gain-2008	2.90%	7.16
	Persistent gain-2012	1.78%	4.39
	New land-2016	3.17%	7.83
	Water-land-water-land	0.55%	1.36
	Water-land-land-water	0.26%	0.64
	Ephemeral land-2012	0.35%	0.87
	Ephemeral land-2008	0.69%	1.72
	Persistent water	39.95 %	98.72
	Total	100.00 %	247.11

Project Location

Prepared by:
U.S. Department of the Interior
U.S. Geological Survey
Wetland and Aquatic Research Center
Baton Rouge, Louisiana
Prepared for:
Louisiana Coastal Protection and Restoration Authority
New Orleans Field Office

DOI: 10.5066/P91BNNS0

Appendix D7. 2005, 2008, 2012, and 2016 Land/Water Classifications and Matrix for CRMS4407.